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ENGINEERING DATA RELATING TO HIGH-TENSION TRANSMISSION SYSTEMS

SUB-COMMITTEE REPORT PREPARED BY THE CHAIRMAN

THE present report is an analysis of the engineering data received from 25 power companies, operating high-tension transmission systems, in answer to a printed list of questions prepared by the High-Tension Transmission Committee of the year 1912-1913, and sent by that committee to 105 power companies operating at 25,000 volts and over.

The present Engineering Data Sub-Committee has received the replies to these questions and has analyzed the data therein contained as hereinafter presented. In making this analysis, the main purpose has been to present, as far as feasible, the data having general interest in a form which shall at the same time be compact and easy of assimilation. A considerable part of the data which is statistical has been consolidated in tables which show in parallel columns for the several reporting companies various items of interest returned. A second portion of the data received could be presented more intelligbly under the various topical headings to which it related, and has been so offered. As a matter of convenience the reporting companies have been listed, with a brief statement as to the character of each plant and an abbreviation of the title assigned to it for the purpose of identification, to avoid the reprinting of the full names of companies a large number of times in the body of the report. In addition to the listed data, the companies have furnished a large number of blue-prints, drawings and maps, many of which contain valuable designs and constructional details. Much of this material has been reproduced in the form of cuts at the end of the report. To facilitate examination and to economize space most of this matter has been redrawn to present the salient information free from nonsignificant detail. Where useful, dimensions and similar data have been given in the reproduced drawings.

The original reports returned from the companies will be on file at Institute headquarters and open to the inspection of any Institute member, should further details be desired. Furthermore, in the list of companies below are given the name and address of the person by whom the report was submitted, and it is very possible that further information with regard to the apparatus or practise of that company referred to in this report, could be obtained by direct application to such person.

Neither the Engineering Data Sub-Committee nor the Institute assumes any responsibility for the correctness of the information here reported. The sub-committee has endeavored, however, to give a clear and fair report of the information offered.

The sub-committee wishes to express its thanks and appreciation for the freedom with which companies have reported and to acknowledge its obligation for the large amount of personal attention and thought which was required on the part of reporting engineers to answer the very comprehensive list of questions that was submitted. Certain reports in particular should receive especial mention as showing an unexpected amount of painstaking description and discussion of some of the most important and delicate problems confronting high-tension transmission engineers. The sub-committee believes that the comparison of experiences and practise herein set forth cannot fail to be of much value to the profession and will certainly be of great assistance to those engineers having high-tension plants to establish who have not the time and opportunity for the extended research that is necessary in the case of plants of the first magnitude.

LIST OF REPORTING COMPANIES

100,000-VOLT GROUP

MISSISSIPPI RIVER POWER CO., (Miss. P.) Keokuk, Ia.—St. Louis, Mo.
Stone & Webster Eng. Corporation.

The data returned cover a double trunk line electrification. It represents the very heaviest type of large capacity transmission line and is recently completed. The report is a most valuable one.

GREAT WESTERN POWER CO., (Gt. W'n. P.) California
P. T. Hanscom, Asst. to the President, 233 Post St., San Francisco, Cal.

The data returned cover a large capacity trunk line electrification across the state of California from the Sierra Nevada Mountains to the neighborhood of San Francisco. A very valuable report. This plant has been operating several years.

YADKIN RIVER POWER CO., (Yad. R. P.) North Carolina

R. J. McClelland, Chief Engineer, Electric Bond & Share Co., 71 Broadway, New York.

The data returned cover a trunk line electrification of medium capacity, connecting a large hydroelectric development supplementary to a previously existing system, and is but recently finished. A valuable report.

PACIFIC GAS & ELECTRIC COMPANY, (Pac. G. &. E.) Central California. San Francisco.

This is one of the largest, oldest and most diversified companies in the country.

CHILE EXPLORATION CO., (Ch. Ex.) Chile.

Percy H. Thomas, Consulting Electrical Engineer, 2 Rector St., New York.

This line, which is not yet in operation, is a large capacity trunk line for supplying power for operating a very large copper mining development, including the electrical refining of the metal at the mine. It is notable as transmitting power from a power-house at the ocean to a mine at an elevation of 9000 feet.

NOTE. One company ("X") did not wish its name used. It is a large system in a bad lightning district. It has a very large, widely distributed power load.

85,000-VOLT GROUP

MEXICAN LIGHT & POWER CO., (Mex. L. & P.) Necaxa to the City of Mexico.

C. B. Graves, General Manager, Apartado 124, bis., Mexico, D.F.

The data returned cover a number of transmission lines in a very large system which collects power from a number of power stations and distributes it over a wide range of territory. This plant has been operating for a number of years. A very full and useful report.

APPALACHIAN POWER CO., (Ap. P.) Bluefields, W.Va.

H. W. Buck, Viele, Blackwell & Buck, 49 Wall St., New York.

This plant, which is very modern, illustrates the problem of the distribution of power in moderate quantities to a distributed load. It has been operating but a short time. A valuable report.

SOUTHERN SIERRAS POWER CO., (Sou. S. P.) Southern part of California.

R. G. Manifold, Engineer, Riverside, Cal.

The data returned cover a high-voltage construction for an extremely long-distance transmission operated in conjunction with a previously existing system of large extent. It operates at present at a lower voltage than ultimately contemplated. A valuable report.

PENNSYLVANIA WATER & POWER CO., (Pa. W. &. P.) Holtwood to City of Baltimore.

J. A. Walls, Chief Engineer, Baltimore, Md.

The data returned cover a heavy trunk line electrification in a very difficult lightning district, receiving power from the well-known Susquehanna River hydroelectric development. The engineering of this line has been particularly carefully worked out and the report is especially full and valuable.

60,000-VOLT GROUP

WASHINGTON WATER POWER CO., (Wash. W.P.) Washington.
O. F. Uhden, Chief Engineer, Spokane, Wash.

The data returned cover a new trunk tower transmission line and also standard 60,000-volt wood pole construction. This is part of a very large and widely distributed system. A valuable report.

TORONTO POWER CO., (Tor. P.) Ontario. Canada.
F. G. Clark, Chief Engineer, Toronto, Ont., Canada.

This is a large-capacity trunk line through a bad lightning district, from Niagara Falls to Toronto. A good report.

SAN JOAQUIN LIGHT & POWER CORP., (San. J. L. & P.) California.
Lloyd N. Pearl, General Superintendent, Fresno, Cal.

This is a widely spread distribution system using wooden poles in the Southern Central district of California. A particularly dry climate.

NIAGARA, LOCKPORT & ONTARIO POWER CO., (Niag. L. & O.P.) Western New York.
L. C. Nicholson, Marine Bank Building, Buffalo, N.Y.

This is a double trunk line through the western part of New York State in a very bad lightning district. This plant has been in operation a number of years and its engineering has been very carefully studied. A valuable report.

PORTLAND RAILWAY, LIGHT & POWER CO., (Port. R.L. & P.) Oregon.
O. B. Coldwell, General Superintendent, Broadway, Portland, Ore.

The data returned cover some of the more modern construction of an extensive generating and distribution system of large capacity. A valuable report.

SOUTHERN CALIFORNIA EDISON CO., (Sou. C.E.) California.
J. A. Lighthipe, Los Angeles, Cal.

The data returned cover a portion of a large and well-known system feeding into Los Angeles, Cal.

CHIPPEWA VALLEY RAILWAY, LIGHT & POWER CO., (Ch'a. V.R.L. & P.) Wisconsin.
Eau Claire, Wis.

WESTERN STATES GAS & ELECTRIC CO., (W. St's. G. & E.) California.
Stockton, Cal.

The data returned cover an extensive distribution system in Central California. Wood-pole type of construction.

PUGET SOUND TRACTION, LIGHT & POWER CO. (P. S. T. L. & P.) Wash.
John Harisberger, M. T. Crawford, S. C. Lindsay, Seattle, Wash.

The data returned cover a large generating distribution system around Seattle, with modern transmission lines. A portion of the plant has been in operation for a number of years.

CITY OF SEATTLE LTG. DEPT. (City S. L. Dpt.) J. D. Ross., Seattle, Wash.

25,000-50,000-VOLT GROUP

UTAH LIGHT & RAILWAY CO., (Ut. L. & R.) Utah.

O. A. Honnold, Electrical Engineer, Salt Lake City, Utah.

The data returned cover a portion of a very extensive system centering around Salt Lake City, Utah.

CANADIAN NIAGARA POWER CO., (C.N.P.) Niagara Falls, Canada, and Buffalo.

L. E. Imlay, Superintendent, Niagara Falls, N.Y.

The data returned cover a trunk line from Niagara Falls, Canada, to Buffalo. It represents four heavy capacity lines, parts of which have been in operation a number of years.

MT. WHITNEY POWER & ELECTRIC CO., (Mt. Wh'y. P. & E.) California.

Fred G. Hamilton, Superintendent, W.D., Visalia, Cal.

A transmission distributing company located in irrigating district of Central Southern California.

UNION TRACTION CO. (Un. T.) Indiana.

G. H. Kelsay, Anderson, Ind.

The data returned cover construction of an interurban electric railway system of wide extent.

TABLES

Tables I to V, inclusive, herewith, give statistical information as to the several companies and are self-explanatory. Where the information submitted has been too extended to incorporate in the table, it is given in the following notes.

NOTES REFERRED TO IN TABLES

NOTE 1. Angles are turned by shortening standard spans and taking only part of angles exceeding 10 deg. on any one pole. Below 10 deg. the following table is used:

Angle	Span
0 deg.	600 ft. tangent.
2	500
4	400
6	300
7	200
8½	100
10	50

On angles over 50 deg. the last tangent span is made 300 ft.—the first and last angle spans are 50 ft. with an angle of 5 deg., and subsequent spans are 50 ft. with 10 deg. angle each.

Vertical angles are similarly handled.

NOTE 2. Right angles and heavy angle corners are turned by specially guyed dead-end poles, Fig. 6, —angles under 10 deg. turned by standard poles guyed, and angles from 10 to 30 deg. are made on two or more poles. Vertical angles are not specially constructed except as to guying.

NOTE 3. Mex. L. & P. reports that the altitude is important. Gaps are set as follows:—Necaxa, altitude 2950 ft., voltage 85,000, gap 6 in.; El Oro, altitude 8000 ft., voltage 81,000, gap 6 in.; Pachuca, altitude 8000 ft., voltage 84,000, gap 7 in.

NOTE 4. Lumping together total interruptions and partial interruptions, and in the latter including even minor losses of load, such, for instance, as a direct-current breaker on a synchronous motor-generator set opening up, although the synchronous apparatus holds in, we have the following percentages:—

Lightning	50	per cent
Distributing cables	25	"
Miscellaneous	25	"—including buzzards on transmission line, operators' faults, and machinery breakdowns.

NOTE 5.

Floods and washouts on line	50	per cent
Pole tops burning off or failure of insulators	25	"
Errors in operation	5	"
Malicious interference	20	"

NOTE 6.

Lightning	70	per cent approx.
Wind, rain, sleet, etc.	10	" "
Interference	5	" "
Errors	5	" "
Miscellaneous	10	" "

NOTE 7. a. 1907—1912, possibly 10 or 12.
1912, possibly 10 or 12.
1913, possibly 5.

It is almost impossible to tell whether these insulators were punctured resulting in their breaking, or whether they cracked due to a spill-over and then punctured. With the new insulator or Hirt type very little damage can be done by spill-over.

b. From 1907—1912, about 150 insulators lost.
1912—about 75 insulators lost, and about 200 others changed on account of cracks.
1913, about 200 insulators changed on account of cracks and probably 50 insulators lost.

NOTE 8. The telephone system is protected by:—

a. A No. 8 steel ground wire carried on the same crossarm as the telephone wires, and on the side toward the transmission line.

b. Drain coils at terminals and at the two substations.

c. Vacuum arresters and spark gap at all telephone stations permanently connected to line. Aluminum cell arresters at terminals and at Hulls substation.

d. Insulating transformers at power house and substations.

NOTE 9. Telephone wires transposed according to "A", "B"-"C"-"B" system. "A" transposition between pairs; "B" and "C" transposition between wires of each pair.

NOTE 10. No standard distance for transposition. Our 28-mile two-circuit tower line has three complete cycles in each circuit. The majority of pole lines have a transposition every mile (one cycle every three miles). Where our high-tension lines parallel foreign telephone or telegraph lines, transpositions are made every 1/3 mile.

NOTE 11. Long fuses (30 inches long) with spark gap to ground. At all stations "bleeder" coils with middle point grounded are installed. Operator must stand on insulated platform to use telephone.

NOTE 12. Reactance coils are used in main low-tension buses in the power house between groups of generators.

NOTE 13. Between the low-tension bus and the transformers at the power house, and between certain sections of the bus at the power house and at the substation.

Short-circuit current on transmission line at full voltage in power house, right outside the power house, is about 5 to 6 times normal full load current at start.

Without these reactances the starting wave of the short-circuit current at the same point would be about 8 to 9 times full load current.

No objectionable features. These coils have been in service all year 1912 and 1913.

NOTE 14. The coils will be located between sections of 12,000-volt generator busbars and will limit the flow of current to the capacity of the bus section which it protects.

NOTE 15. Coils will have 6 per cent reactance, and will be placed close to terminals of the 12,000- and 15,000-kw. steam turbines.

NOTE 16. The factor of safety of new poles is entirely up to the judgment of the designing engineer, and depends greatly on the climate, kind of soil and economic conditions. Our towers were built to stand if all conductors were cut on one side, and no allowance was made for the tendency of the ground wires to support the tower.

Specifications for Towers.

Each crossarm will be sufficiently strong to withstand a horizontal strain in any direction applied at the end of the crossarm of 5000 pounds; and a vertical strain applied at the end of the crossarm of 1000 pounds.

Each ground wire support will be sufficiently strong to withstand a horizontal strain in the direction of the line of 8000 pounds and a vertical strain of 1000 pounds.

Each tower will be sufficiently strong to successfully resist the turning moment due to the application of a horizontal strain in the direction of the line of 5500 pounds applied at the point of support of either ground wire; also of a horizontal strain in any direction of 3000 pounds applied to the points of support of any three of the conducting wires. It will also be sufficiently strong to successfully resist an overturning due to a strain parallel with the line of 5500 pounds applied at the points of support of the two ground wires or a total of 11,000 pounds; also to a strain at right angles to the line of 5000 pounds applied at the points of support of the two ground wires or a total of 10,000 pounds; also to a strain of 9000 pounds in the direction of the line, which load will be considered as concentrated at the intersection of the middle crossarm and the center line of the tower, and simultaneously a horizontal strain of 500 pounds at the points of support of each of the six conducting wires and two ground wires or a total of 4000 pounds, which strain will be in a direction transverse to that of the line; also of a stress of 12,000 pounds applied horizontally at center of gravity of wires either at right angles or parallel to the line. Accompanying the above mentioned horizontal stresses will be a vertical downward strain of 500 pounds applied to each of the supports of the six conducting wires and two ground wires.

In addition to the above specified stresses each tower will be subjected to stresses due to its own weight and to a wind pressure in a horizontal direction of twenty pounds per square foot on the superficial area of the tower. The strength of each tower will be sufficient to resist the combined action of all of the above stresses without permanent distortion.

NOTE 17. Old insulators assembled test 120,000 volts for 1 min. New insulators, each disk tested with a low capacity transformer having steep wave front for 2 min. of continuous static discharge over insulator. Strain insulators same test.

NOTE 18. A special test tower was constructed and tested with following tests and all towers were built as duplicates of test tower:—

Test No. 1. A horizontal pull of 12,500 lb. in a direction parallel or at right angles to the lines will be applied at the intersection of the middle crossarm and the center line of the tower.

Test No. 2. A horizontal pull of 4,000 lb. in a direction parallel to the line and applied at the ends of any two crossarms (aggregate pull 8,000 lb).

Test No. 3. A horizontal pull of 6,000 lb. in a direction of the line applied at the end of any crossarm.

Test No. 4. A vertical load of 1,500 lb. applied at the end of any crossarm.

The tower must withstand the above force without permanent distortion in any member, and if such distortion should take place the contractor must replace such members with others until the tower successfully meets the requirements of the tests.

All of the standard towers covered by this contract must then be constructed strictly in accordance with the design and sizes of material contained in the successful test tower.

NOTE 19. On three of the present four 22,000-volt circuits from Niagara Falls to Buffalo on the Canadian side are in use electrose insulators which have been in service a considerable number of years. The fourth line which was installed in 1912 also uses electrose insulators but of a radically different design planned to be puncture-proof in severe impact tests. Test and forms of these insulators are described in the Trans. A. I. E. E., p. 2121, Vol. XXXI, meeting December 1912.

NOTE 20.

Winds, floods, fires, etc.	35	per cent
Interference, blasting stumps, etc.	20	"
Lightning,	5	"
Failure in equipment or insulators,	15	"
Miscellaneous and unknown,	25	"

NOTE 21. The foundations of towers consist of 7-ft. legs with foot piece, the whole generally loaded with stone and well backfilled.

NOTE 22. Material of insulators porcelain with slate glaze. (Slate glaze shows up arc smoke marks better than brown glaze and attracts the attention of gunners less, but does not show up broken petticoats as well).

NOTE 23. The towers were built for two ground wires, but only one ground wire located on apex of tower was erected. This makes the horizontal spacing from ground wire to conductor $7\frac{3}{4}$ ft. and the vertical spacing $7\frac{1}{2}$ ft.

NOTE 24. All standard towers set on earth stubs, while the heavy towers are set in concrete.

TOPICAL TREATMENT

A large number of comments made by the various reporting companies on a number of topics of especial interest to engineers are here grouped together under their appropriate subjects as follows:

LONG SPANS (QUESTION A-19)

The following notes of interest were returned:

Miss. P. Longest span with standard tower and conductor 1425 ft.

The maximum span used on this line is 3200 feet, and occurs at the crossing of the Missouri River. This and other long spans are shown in plan and profile on the accompanying drawings (Figs. 30, 31 and 33.) The conductor cable in these spans consists of a $\frac{5}{8}$-in. high-strength galvanized 19-strand steel core overlaid with 20 strands of No. 10 B. & S. gauge hard drawn copper wire. The cable is filled with a compound for the exclusion of air and moisture. Each circuit is carried on a single tower line, conductors in a horizontal plane, spaced 20 ft. apart, with two ground wires 10 ft. above at point of support. These river crossing towers were especially designed and vary in height from 60 to 230 ft. above foundations. See drawings.

Gt. Wn. P. One span 2300 ft. on special towers; one 2740 ft.

with No. 000 B. & S. "Minot" stranded wire; conductor balanced by counterweights to give uniform tension—Figs. 3 and 4.

Mex. L. & P. One 1400 ft. with a difference in elevation of 350 ft.; cable size and towers standard.

Pa. W. & P. Longest span with standard conductors and towers 1280 ft. Longest span 1800 ft. with No. 0000 B. & S., 7-strand hard drawn copper and towers 115 ft. high over all above foundations. Span sag 120 ft. (6.7 per cent). Distance between conductors, vertically 10 ft., horizontally 15 ft.—Ground wires above conductors—no trouble.

City S. L. Dpt. Longest span 780 ft. standard double-pole construction.

Wash. W. P. One 1500 ft., $\frac{1}{4}$-in. "Siemens-Martin" steel as conductor.

San. J. L. & P. Span across Kings River at Piedra, six 3/0 aluminum cables, carried about 1700 ft. across river and anchored on hillsides to cedar poles. Two sets of three wires each are attached to two poles, wires in a vertical plane six ft. apart and attached to poles with two Locke No. 273 strain insulators. Guys are placed for each wire and run to anchorage in rocks. About 200 ft. sag is obtained with wires clearing river about 150 ft. All wires swing in unison in a high wind and no trouble has been experienced.

Niag. L. & O. P. See drawing, Fig. 34.

C. N. P. See drawing, Fig. 8. The transmission line crosses the Niagara River at Buffalo where there is a span of 2192 ft., from a 150-ft. tower on the American side to a 202-ft. tower on the Canadian shore. The tops of these towers are at the same elevation. The line is then carried over the village of Fort Erie with a span of 1667 ft. to a 61-ft. tower on Bertie Hill. The top of this tower is 107 ft. below that of the high tower. The minimum clearance of the cables above the river is 130 ft. On the high towers the cables are arranged on 15-ft. triangles and on the Bertie Hill tower on 10-ft. triangles.

The twelve conductor-cables are made up of 19 strands of No. 10 B. & S. gage bi-metallic wire and are stressed up to 5400 lb. This tension is kept constant by counterweights on the Buffalo and Bertie Hill towers. The counterweights are supported by steel cables which run over sheaves at the top of the towers and are connected to each bi-metallic cable through two pairs of spool insulators. Drop cables pass down and through the tower to the Buffalo terminal station and on the Bertie Hill tower to the busbars. The busbars and switches are so arranged that any circuit on the pole lines can be connected to any circuit on the long spans. At the high tower, the cables are connected to galvanized iron chains which rest on insulated saddles and extend about 13 ft. on each side of the tower. Jumper cables are carried over the saddles.

In addition, spans of 800 and 1435 ft. were reported by other companies and no cases of trouble.

SPECIAL FEATURES OF CONSTRUCTION (QUESTION A-20)

The following notes relate to special features of interest in construction:

Ap. P. All suspension insulators are ballasted with 30-lb. cast iron weights. (See Part I of this volume of TRANSACTIONS, page 133).

Port. R. L. & P. Experience has shown that it is cheaper and quicker to erect steel towers in position from the ground up.

ANCHOR TOWERS ON TANGENTS (QUESTION B-13-15).

The following reports were made on the use of anchor towers on tangents:

Miss. P. Approximately every mile.

Gt. Wn. P. Average every two miles—designed to stand with all wires cut.

Ap. P. Two per mile—designed to stand with all wires cut.

Sou. S. P. Every five miles, designed for 24,000 lb.

Pa. W. & P. At least every fifth tower—on average five to mile.

San J. L. & P. Poles guyed both ways every half mile, will stand with three conductors cut.

Niag. L. & O. P. Every mile on steel towers; every half mile on "A" frames; all to stand with all three conductors cut.

Sou. C. E. No, use line guys.

Ut. L. & R. Every 1½ to 3 miles, according to wind conditions; designed to stand 7000 lb. at center crossarm in addition to stress on regular line towers.

C. N. P. Only at two ends of line and two intermediate curves; designed to stand all conductors cut.

DETERIORATION (QUESTION A-25)

The following interesting notes on deterioration were received:

Gt. Wn. P. Slight rusting where towers were not properly galvanized. Wires corrode.

Yad. R. P. Line two years old—no deterioration noticed.

Pa. W. & P. No deterioration observed upon examination of buried portions of galvanized towers. One particular set of gusset plates near top of tower showing signs of rust during 1913; no rust or deterioration elsewhere. No signs of deterioration in conductors. Insulators both on transmission line and in stores showing deterioration, due possibly to temperature expansion effects. About 4 per cent of insulators examined show such deterioration, not due to electrical causes.

Wash. W. P. We have noted no deterioration in conductors. Some insulators placed in service in 1904-1906 indicate that they may have deteriorated, but as the manufacture of porcelain at that time was far less efficient than now, no results of long time tests on those would indicate what will obtain on the ones of later manufacture. Towers were placed in 1910, and no deterioration has been noticed.

Tor. P. Except for some deterioration of ground wire and hemp core of conductor, no deterioration noticed.

San J. L. & P. No deterioration noticed as yet—60,000-volt system in use only three years.

Niag. L. & O. P. Galvanized towers develop rust spots in about seven years. Insulators to some extent deteriorate by puncture of an occasional skirt. No noticeable deterioration of cable except by occasional burning by arcs.

Port. R. L. & P. The transmission line has been in service less than two years and we have, therefore, no observations of deterioration except in the matter of insulators, there having been a considerable number of failures in suspension insulators and insulators in a strain position since the line was put in service.

Sou. C. E. Insulator shells crack, presumably due to expansion of cement or steel pin.

Ch'a V. R. L. & P. Insulators give more trouble with age.

Ut. L. & R. Wood poles with carbonized butts last 10 years in this climate.

Pug. S. T. L. & P. None, if proper factors of safety were observed in original installations. Steel towers have to be painted every two years, if not galvanized. Cedar poles rot off at the ground in from 15 to 20 years.

City S. L. Dpt. Poles rot at ground line.

DEFLECTION OF SUSPENSION INSULATORS (QUESTION B 20-21)

As to how much angular deflection of conductor was assumed under wind conditions and how much was actually observed, the following data were reported:

Miss. P. 26 deg. 45 min., with ½ in. ice, assumed.

Gt. W'n. P. 45 deg. assumed.

Yad. R. P. 45 deg. assumed.

Ap. P. 30 deg. on swinging of strings; held down by 50-lb. weights.

Sou. S. P. 45 deg. assumed—45 deg. observed on swings.

Pa. W. & P. Approximately 60 deg. Probably never more than 30 deg. angular deflection from vertical due to wind observed under either steady wind conditions or swings. No good records on actual angular deflection. Conductors do not swing violently, and angular deflection is not the same at all points in a span for one conductor, but is the same for all conductors. See drawing, Fig. 54.

Wash. W. P. 50 deg. assumed, 36 deg. observed.

Ut. L. & R. 60 deg. from vertical assumed, this value observed in swings.

DESIGN FACTORS OF SAFETY (QUESTION B-22)

As to the factors of safety provided in conductors, towers, against overturning foundations, and overhead ground wires, the following data were reported:

Miss. P. Conductors 2, towers 3, foundations 2, ground wires 2.

Gt. Wn. P. Conductors 2, towers 2, foundations 3, ground wires 3.

Yad. R. P. Conductors 25,000 lb. per sq. in.

Mex. L. & P. Conductors 2 and 3, foundations 1.5.

Ap. P. Conductors 2, 3, towers 2, foundations 5, ground wires 10.

Sou. S. P. Conductors 2.5, towers 1.7, foundations 1.7.

Pa. W. & P. For conductors (alum.) up to elastic limit—towers tested for maximum designed strength at factory—foundations practically 4—ground wire just up to elastic limit.

Wash. W. P. For conductors elastic limit, for towers 1, for foundations 1, for ground wire 1. These factors are taken in view of the fact that the maximum load conditions assumed were very severe.

San. J. L. & P. For conductors 6, for poles 3.

Niag. L. & O. P. For conductors 1 (elastic limit), towers 2, foundations, 2.

Sou. C. E. For conductors 22,000 lb. per sq. in working stress.

Ctiy S. L. Dpt. Factor for conductors of 3 over elastic limit.

OVERHEAD GROUND WIRES AS PART OF STRUCTURE (QUESTION B-23)

In answer to the question as to whether overhead ground wires are relied upon as part of the line structure most of the companies replied *no*, but the following comments were received.

Yad. R. P. Yes.

Pa. W. & P. Ground wire gives some stiffness lengthwise of line, damping longitudinal vibrations of towers, but is not relied on as part of the mechanical supporting structure.

Ut. L. & R. No, but it undoubtedly acts as a guy wire.

CUTTING OUT OF LOAD (QUESTION C-1)

A loaded circuit is usually cut off by an oil switch, sometimes on high tension, sometimes on low tension. The following replies are noted:

Gt. Wn. P. Drop generator load and open generator oil switch on low-tension side. Do not switch on high-tension side.

Yad. R. P. (a) Reduce voltage 60 per cent and then open low-tension oil switch. (b) Open low-tension oil switch at full voltage. (c) Open high-tension oil switch at full voltage.

Mex. L. & P. Cut out sections of line one at a time loaded or unloaded. Experience shows that this method gives less trouble from surges on oil switches and switch bushings.

OPENING SHORT CIRCUIT. (QUESTION C-2)

To open a short circuit that holds on, the following companies reduce the voltage of the generators:

Miss. P., Gt. Wn. P., Sou. C. E., C. N. P.

Note also the following comments:

Sou. S. P. The hydroelectric plants are tied in by non-automatic switches on the low-tension side while the steam plant has oil breakers with definite time limit relays on the low-tension side. The high-tension switches in the main tower line are of the Bowie air-break type and are non-automatic. As operated at present, when short circuit occurs on tower line, the steam plant breakers clear the southern end of the system of trouble, leaving the steam station with all load in that territory. The hydroelectric plants then drop voltage to low value and test for location of trouble.

Sou. C. E. Separate main system into sections and cut out step-up transformers on high-tension side.

AUTOMATIC OVERLOAD RELAYS (QUESTIONS C 3-8)

Automatic overload relays are generally used, and in many parts of the various systems. The majority are definite time limit or inverse time limit.

The overload settings run from 100 per cent to 300 per cent overload, and the definite time limits from ½ to 10 sec.

A half-dozen companies use overload relays of progressively greater time element distributed from the load to the generator.

Miss. P. Use inverse time limit automatic overload breaker to cut apart groups of generators on the 11,000-volt generator busbars.

Niag. L. & O. P. and *Sou. C. E.* report success with this selective action; *Yad. R. P.*, *Mex. L. & P.*, and *Wash. W. P.* report partial success.

Pa. W. & P. Automatic overload circuit breakers are used in connection with 13,000-volt cable feeders, station auxiliary transformers at both power house and substation, and transmission lines, in the last case, however, not the high-tension circuit breakers, but the low-tension circuit breakers of those transformers connected with the line being opened.

In connection with 13,000-volt cable feeders, we use inverse-time relays; for the transformers and transmission line, definite-time relays.

(a) The lowest tripping current for the relays connected with our 13,000-volt cable feeders is 100 per cent overload, based on cable rating; with 700-1400 per cent overload these relays will trip in 1 sec. (inverse time).

(b) The relays for the substation transformers are reverse-power relays set to trip at 50 per cent overload in reverse direction, and connected with a three-sec. definite time element.

(c) The power house transformer relays trip at 140 per cent overload, 7 sec. definite time.

Time-element relays are normally used with progressive timing of the elements. This refers particularly to the relay system used for the 13,000-volt a-c. underground cable system in

Baltimore, of which a part belongs to the Pa. W. & P. Co. and a part to our customers' distributing systems. The larger part of the relays for this system are Type C Westinghouse overload inverse-time relays improved by F. E. Ricketts's compensating coil, which produces a relay curve with less steep characteristic and for heavy overloads can be brought to approach a definite time. Both tests and experience have shown that this type of relay can give good selective action for several relays in series.

Bellows type relays were previously used in this connection but were found to be not sufficiently reliable and were replaced by relays of the type referred to above.

Westinghouse Type C, improved, reverse-power relays with selective element are also used.

These reverse-power relays are used at the substation end of two transmission lines working in parallel. When a short circuit, which is not cleared in any other way, occurs on one line, it will trip the low-tension side of transformers at the substation connected with this line, while overload or time relays will trip the low-tension side of the corresponding transformers at the power house. If the other transmission line is not affected, the reverse-power relays for this line will remain open. In order to give another device (arc extinguishers) time to relieve lightning arcs, these relays for the transmission lines are furnished with definite time-limit relays (W. Type E); these have at present the following setting:

	Circ. No. 1	Circ. No. 2
Power house..................	3 sec.	2½ sec.
Substation..................	1½ "	1 "

The different time setting for the two circuits is chosen in order to prevent one line from opening at the substation, while the other opened at the power house, in case both lines should be in trouble. As soon as one circuit is cleared, an interlocking device prevents the other from opening by any relay action.

If after the clearing of one of the two paralleled transmission lines, the other still shows the trouble, the field will momentarily be taken off all the generators at the power house simultaneously, and restored again.

Should this action not clear the second line, the switches must be opened by hand. Our experience so far shows, however, that permanent line trouble (wires down, etc.) never has taken place on both circuits at the same time.

Pug. S. T. L. & P. Success generally but not always.

Aside from the *Pa. W. & P.*, the *Ut. L & R.* and *Pug. S. T. L. & P.* are the only companies using reverse-energy relays; the former reported "always" act selectively—the latter does not state the result.

Note also *Cty S. L. Dpt.* Use Westinghouse Type C reverse-energy relays which act selectively when the power factor does not drop too low, as on a very heavy short circuit.

DROPPING SYNCHRONOUS LOAD (QUESTION C-9)

The following report that they seldom or never succeed in carrying synchronous load through a heavy main-line short circuit:

Gt. Wn. P., Mex. L. & P., Sou. S. P., Tor. P., San J. L. & P., Port. R. L. & P., W. St's G. & E., C. N. P., Un. T., Cty. S. L. Dpt.

Other reports—

Ap. P. "Sometimes." Lightning arcs are frequently cleared by arc suppressors without losing synchronous load.

Pa. W. & P. Lightning arcs are frequently cleared without the least loss of load, by arc suppressors.

Wash. W. P. We have automatic switches on all lines feeding out of the different stations and when these act properly we very seldom lose any synchronous load.

Niag. L. & O. P. Save synchronous load by automatic arc extinguishers, when arcs only are involved.

Ut. L. & R. Yes, when short circuit is cleared in three seconds.

Pug. S. T. L. & P. Sometimes we can and sometimes we cannot. If the duration of short circuit is three or four seconds, synchronous apparatus always drops out.

CUTTING OUT ONE OF TWO PARALLEL LINES (QUESTION C-10)

In answer to the question whether one of two lines parallel at both ends could be cut out without losing the load the following were received:

Miss. P. Two St. Louis lines parallel at both ends and have been separated in a number of cases automatically without losing the load.

Mex. L. & P. Four lines are operated in parallel and as a rule one line can be cut out without losing the load.

Ap. P. Sometimes.

Wash. W. P. Have such lines but cannot cut them out without losing load.

San J. L. & P. Lines are tied together at load end by tie-breaker set light; at supply end, lines are separated by operator.

Niag. L. & O. P. Have tried this but have abandoned the attempt.

Port. R. L. & P. Yes, but cannot be automatically separated.

Sou. C. E. All main lines, cannot separate.

C. N. P. Cannot separate such lines.

Un. T. Cannot separate such lines.

LOCATING TROUBLE (QUESTION C-11)

Practically all plants sectionalize the line, test with generator voltage and patrol to locate line trouble.

Yad. R. P. Use also a Wheatstone bridge method.

Niag. L. & O. P. Use a special loop test described in the TRANS. A. I. E. E., June 1907.

C. N. P. Uses a loop test.

DISTRIBUTION OF POWER BETWEEN POWER HOUSES AND REGULATION OF VOLTAGE (QUESTIONS 20 AND 21)

No points of especial interest appear in answer to questions on how power distribution between generators and voltage regulation are secured.

EFFECT OF HEAVY SHORT CIRCUIT (QUESTION C-23)

As to the effect of a heavy short circuit near one power station on a large system:

Pa. W. & P. When a short circuit occurs near one power house, the effect of this depends entirely on how long a time it lasts.

(1) If it is a lightning arc on the transmission line it will normally be cleared by arc suppressor.

(2) If it is cable trouble on the 13,000-volt distributing system, it will normally be cleared by opening automatically the proper feeder switches. If the trouble hangs on for more than four seconds the fields of the generators will be destroyed and restored automatically at all three power houses simultaneously.

OPERATION WITH ONE SIDE GROUNDED (QUESTION C-29-31)

In answer to a question as to whether the lines were ever operated with one side grounded, even for a brief period, the following were received:

Pa. W. & P. For a few minutes, no effect; ground was cut off by the time the ground resistance was red hot.

Ut. L. & R. All one night on 28,000-volt circuit; no effect except unbalancing of system.

C. N. P. For about two hours with no effect except a slight unbalancing of current in conductors.

Ap. P. For two hours with no effect.

Wash. W. P. For several minutes causing whole system to be unbalanced.

Gt. Wn. P. For about ½ hour; one oil switch bushing and one string of insulators punctured.

Sou. S. P. "No; effect too severe."

Tor. P. On several occasions for five to fifteen minutes, on one occasion four hours. On the occasion when the system was operated for four hours the ends of the cable that were down were 1000 ft. apart, the ground was highly charged and the barbed wire on the right-of-way fence was also highly charged. A man attracted by the display due to this ground walked into the charged area, then tried to climb the barbed wire fence and was killed. A dog approached the barbed wire fence some distance away and after investigation started for remote regions. Claims were made for damages to cattle. These were paid, although it could not be found that any cattle were really injured.

In operating on a ground we have no means of knowing whether or not the wires are down, and as it is possible that there may be two grounds miles apart with an open circuit in the conductor between, we consider it a very risky thing to continue such operation and would only do so as a last resort.

San J. L. & P. For two and a half hours on 60,000 volts; for one and one-third hours on 30,000 volts. The effect was unbalanced voltage on the particular feeder having a ground; unbalanced load on nearest generating plant, private telephone line out of commission, troubles reported from Sunset and other telephone systems.

Niag. L. & O. P. On one occasion when neutral was not grounded, for two hours; effect "violent."

Pug. S. T. L. & P. For 10 minutes,—severe strains, discharging lightning arresters—telephone wires hot.

RELAYS IN H-T. GROUND CONNECTION (QUESTION C-32)

No plant of those reporting except *Pa. W. & P.* (see below) seems to have any protective relay in the ground connection from the high-tension neutral, except for the fuse of the Nicholson arc suppressor.

VOLTAGE REGULATORS (QUESTION C-41)

The use of Tirrill regulators to control the voltage of generators is almost universal and there appears to be no exception to the satisfaction they give.

FAILURE OF OIL SWITCHES (QUESTION C-43-44)

As to whether oil switches have ever failed to open a circuit, most companies report no trouble, but the following are noteworthy:

Mex. L. & P. Very rarely.

Sou. S. P. No, but signs of distress are often shown. Most of the trouble from oil switches occurs in the breakdown of bushings from lightning or surges.

Tor. P. H-3 oil switches have failed repeatedly when more than four 10,000-kw. generators can feed through them to a short circuit.

Niag. L. & O. P. Yes, from repeated operation on short circuit without overhauling.

Ut. L. & R. 4000-volt, three-phase oil switch on overload.

Sou. C. E. On short circuits; the system has outgrown the size of the switch.

Pug. S. T. L. & P. Oil switches which are type H-3 and K-10 have always opened short circuits successfully but sometimes the switches are nearly wrecked.

WORKING WITH ADJACENT LINE ALIVE (QUESTION C-45)

Practically all companies except *Cty. S. L. Dpt.* work on one of two lines on the same poles or towers when the other line is alive.

WHICH INSULATOR OF SUSPENSION STRING FAILS FIRST (QUESTION C-48).

As to which insulator unit in a string of units is most likely to be injured, note the following:

Gt. Wn. P. Insulator next to line, but in general it is hard to tell.

Pa. W. P. Flash-overs damage first and last units preferably.

Wash. W. P. Nearly always the first and last of the string.

Port. R. & L. No difference.

Ut. L. & R. End disks.

RELATIVE RELIABILITY OF SUSPENSION AND STRAIN INSULATOR STRINGS (QUESTION C-49)

There is a difference in experience as to whether strain insulators are more likely to fail than vertical strings. *Port. R. L. & P.*, *Ut. L. & R.*, *Pa. W. & P.*, *Wash. W. P.*, and *Yad. R. P.* say "no." *Gt. Wn. P.* and *Sou. C. E.* say "yes."

REACTANCE TO BALANCE CHARGING CURRENT (QUESTION C-51)

Sou. S. P. has the following to report about the use of reactance coils to control the power factor of the line.

Shunt inductance coils are used at one end of tower line. These have loading value of 2000 kv-a. and are arranged for being cut in by steps. They have been found valuable in the tieing together of the two systems of plants, enabling the steam plant to get in with the hydro plants with little voltage disturbance, which there would be if steam plant had to raise voltage to value high enough to equal voltage at end of unloaded line; this is about 14 per cent high.

MECHANICAL OSCILLATIONS (QUESTION C-52)

With regard to trouble with mechanical oscillations in the line note the following:

Port. R. L. & P. Trouble occurs at far end of 30-mile, 33,000-volt, 33-cycle line when fed from one generating station only and given a heavy load. Line pulsates and finally kicks out at generating plant.

Ut. L. & R. No trouble except wind swinging suspension insulators enough to break them.

Wash. W. P. No, except that ice falling off the end ones of a group of three spans allows the ice in the middle span to carry this span down too close to conductor in the position below.

Mex. L. & P. Two during earthquakes.

In addition to the above, note the following replies received to a special inquiry about mechanical oscillations:

Gentlemen:

New York, April 13th, 1914.

On January 8th, the Engineering Data Committee, at the suggestion of Mr. L. E. Eustis, Superintendent of the Stone and Webster Engineering Corporation, sent a letter to a number of high-tension power companies asking for any available experience with mechanical vibrations or oscillations of line conductors. You may be interested in the enclosed summary of the replies received. Yours very truly,

PERCY H. THOMAS, Chairman,
Engineering Data Committee.

REPLIES TO LETTER OF JANUARY 8TH RELATING TO EXPERIENCE WITH MECHANICAL VIBRATIONS OR "OSCILLATIONS" OF LINE CONDUCTORS

C. N. P.

"This phenomenon was experienced by us in the aluminum cables which originally spanned the Niagara River between Fort Erie and Buffalo. The vibrations were most pronounced when there was little if any perceptible movement of the air. The cause was doubtless due to the physical constants of the span cables and possibly their supports being such that they would readily respond to slight movements of the air. Our evidence of this is that when the tension was decreased, allowing the cables to sag a few feet below normal, no vibration occurred.

At first we had some trouble with the cable strands breaking at the end supports due to crystallization of the metal. This was overcome by inserting about ten feet of iron chain in each span where the ends are attached to the supports. The chains were then shunted with jumpers to provide the necessary carrying capacity.

After a few years' experience with aluminum cables at the long spans, it was decided to replace them with copper-clad steel cable having much greater tensile strength. These cables are somewhat heavier than the aluminum, but are smaller in cross-section. They are pulled up to the same elevation as the aluminum cables, but, due to the different physical constants, no vibrations have been observed under any weather conditions."

Niag. L. and O. P.

"Please note that we have frequently noticed such oscillations but never have found any harm to result from them. Such oscillations are particularly noticeable on long spans, although they occur to some extent on all spans."

Oregon E. R.

"Wish to say that we have had no serious trouble from this source, and have had no data or experience along this line that would be of interest."

Tor. P.

"We have no spans comparable to the Mississippi River crossing at Keokuk, Iowa. We have, however, given consideration to crossing the Niagara River where we have had to figure on 4000- and 6000-foot spans. It was necessary for us to consider mechanical oscillations of the cables due to changes in temperature, ice loading, wind, and the vibrations that would be started by short circuits, and we concluded that proper spacing, counter-weighting and keeping the cables at suitable temperature by means of local currents from insulated transformers or generators, would afford us ample protection.

We have no spans over 1000 feet on our existing transmission lines and have had no troubles that we can assume are directly due to mechanical oscillations. We have had line interruptions during sleet storms which could probably be accounted for in no other way."

Pa. W. & P.

"The possibility of such phenomena was anticipated at the time our transmission line was designed and a special endeavor was made to so design the line as to prevent such oscillations. We believe that the many anchor towers used and the attention given to the conductor sags is responsible for our freedom from such trouble.

As stated in the previous answers, we did experience some troubles owing to the ground wire being stretched too tightly, so that it hummed and caused considerable vibration of the towers. It was found necessary to cut in additional slack into the ground wire. The ground wire had originally been strung very tightly in order to avoid interference between ground wires and conductors, due to the possibility of sleet collecting on the ground wire while being absent on the conductors. Also a tight ground wire was considered advisable in order that its period of vibration longitudinally might be quite different from that of the conductor."

"We have no evidence of mechanical oscillation on our 1800-ft. span river crossings."

From Mr. Magnus Swenson, President,
Southern Wisconsin Power Company, Madison, Wis. (dated 1/21/14)

"In answer to yours of the 8th will say we have experienced no trouble from mechanical oscillation on our line, nor has the Peninsular Power Company in the northern part of this state."

G. Wn. P.

"Will state that we have no record of any one having observed this phenomenon on our lines."

Pac. G. & E. (dated 1/20/14)

"This company maintains a large number of long spans on transmission lines, these varying from 200 to over 4000 ft. in length. On spans up to 1500 or 2000 ft. the conductor material is not of great importance, our experience being that there is very little choice between copper, aluminum, copper-clad steel and other materials.

On spans of more than 1500 ft. we have found it desirable for mechanical reasons, to use either copper clad, or steel conductors.

The longest span we have is that known as the "Carquinez Strait crossing," where the distance between supports is 4427 ft. The conductors on this crossing are of 7/8-in. plow steel, having ultimate tensile strength of 200,000 lb. per unit cross section. These spans have been in successful operation at 60,000 volts for 13 years. There is a small amount of vibration in the conductor at the point of support during days when there is no wind blowing, but during times when the wind is blowing the hardest there is little if any vibration whatever at this point.

A year ago one of the conductors of this span was taken down and a section near the supporting saddle was tested to determine whether or not there had been any appreciable deterioration of the metal either from crystallization or from electrical causes. A careful analysis and test showed that the cable was in apparently as good condition as it was the day it was erected.

On another line we have installed a large number of spans of 6/0 stranded aluminum, ranging from 1200 to 1800 ft. in length. No trouble has been experienced on spans of this length from the causes mentioned; in fact, this particular line is considered one of the most reliable that we have.

In a few instances trouble has been experienced from the vibration of the conductor, which has resulted in the latter breaking at the point of support. These instances, however, are very rare and we have attributed the trouble to the fact that the length of span and tension in same were just right for the wind to cause excessive vibration. In every instance where this trouble has occurred, the insulator has been the ordinary pin type. The trouble has been corrected by setting another pole, and thus introducing another point of support in the vibrating span."

From Mr. Chas. I. Burkholder, General Manager,
Southern Power Co., Charlotte, N. C. (dated 1/20/14)

"I have to advise you that on our lines having suspension insulators we have not had any trouble due to mechanical oscillations of line conductors, except in the case of unequal distribution of load due to sleet unloading from the lines. This has never occurred when the sleet was forming but has occurred when the sleet was falling off of the wire, in cases where it happened that the sleet fell off of one wire, we will say, in a given span, and remained on another wire, and where the opposite occurred in an adjacent span. This would cause an accumulation of sag in the unloaded span, and in some cases the accumulation of this sag has been enough to cause an actual contact of wires which were strung with a 10-foot vertical spacing. To obviate this, we lengthened our middle crossarm 3½ feet at each end."

Wash. W.P.

"I beg to state that we have never noticed any mechanical oscillations of our line conductors.

At one time we had some trouble which we were unable to account for, and thought that possibly it might be due to such mechanical oscillation. To satisfy ourselves on this point we short-circuited one of our 60,000-volt lines, about four miles from our Little Falls power house, without noticing any oscillation whatever in the conductors. This short-circuit was thrown on the line when it was connected with a 5000-kilowatt generator at the station, and as far as I remember now the automatic switch was set for ten seconds definite time limit."

Port. R. L. & P.

"We wish to state that we have not experienced any trouble. We have observed, however, the presence of waves along the conductors in an 1800-foot river crossing span. These waves appeared to travel along the conductors even on a quiet day. They were apparent only by listening to the insulators at the supports and manifested themselves in very much a similar manner to blows struck against the conductors with a wooden mallet. As the crossing span was removed within a year after its installation, and has not been replaced, we have no occasion to report actual trouble resulting from the waves. The crossing span supports are each located a short distance from railroad tracks and the waves which we observed appeared to have been started by passing trains."

From Mr. A. J. A. Kean, Chief Operating Engineer,
The Michoacan Power Co., Guanajuato, Mexico. (dated 2/10/14)

"In this connection we wish to advise you that we had this trouble on one of our transmission lines some two years ago and were able to eliminate the difficulty by using special hangers made in the form of a bow. If Mr. Eustis would care to send to us details regarding his trouble we may be able to supply him some information which will be of assistance to him."

From Mr. W. B. Stone, Chief Electrical Engineer,
Jhelum Power Installation' Baramulla-Kashmir, India.

"I beg to inform you that formerly when we had long river spans we experienced trouble which I attribute to this cause. The line wires became crystallized through fatigue close to the clamps on the insulators, and when the first fall of snow came they invariably carried away at this point. We have now removed all long spans."

From Mr. C. A. Sylvester, General Manager,
The Rio de Janeiro Tramway, Light and Power Co., Limited,
Rio de Janeiro, Brazil.

"We have had no trouble which could be traced to mechanical oscillation of our transmission line conductors.

Our 88,000-volt transmission consists of 3/0 conductors erected on Riter-Conley type of steel towers, six conductors per tower. We have several spans exceeding 500 meters, the greatest span being 590 meters. Observation of the oscillations indicate a considerable side swing during heavy winds, but the wires apparently always maintain their spacing of eight feet. This is probably due to the fact that they are of the same weight per foot, same diameter, and are erected with the same tension. There is of course no unequal loading due to sleet.

It has been suggested that the vibration and oscillation of the wires may tend to break the conductors at the insulators. We have up to the present time observed no effect of that kind. The lines have been erected since 1907."

Location of Lightning Arresters (Question C-2)

Lightning arrresters are freely located either inside or outside, and universally close to the outlet of a station.

DURATION OF DISCHARGE ON ELECTROLYTIC ARRESTERS (QUESTION D-10)

There is no report of over 1 minute of actual continuous discharge on an electrolytic arrester. At least two companies cut them out if they begin to discharge steadily.

EFFECTIVENESS OF OVERHEAD GROUND WIRE

With regard to the opinion of companies on the effectiveness of overhead ground wires as a protection against lightning, note the following:

Mex. L. & P. We have had overhead ground wires on our high-tension transmission lines for the past six years. In practical experience we have found that this has given us an excellent protection. The number of cases of trouble due to lightning has been enormously reduced since the installation of these ground wires. We can definitely state that we consider their installation as effective and desirable.

Ap. P. There is evidence in favor of the effectiveness of overhead ground wires but it is not conclusive.

Pa. W. & P. We have no reason to believe that the overhead ground wires have been of any benefit against lightning troubles.

Ch'a V. R. L. & P. We have wood pole lines 26 miles long without ground wire; there is a 12-mile extension with ground wire, same insulators and crossarms used; never had an interruption from lightning on 12-mile line; have 7 or 8 per season on 26-mile line and have many bad insulators that do not shut down line.

Ut. L. & R. Overhead ground wires on tower lines undoubtedly reduce static disturbances, as interruptions are much less frequent than before.

SPECIAL PROTECTIVE DEVICES (QUESTIONS E-1-4)

In certain systems, devices operating through circuit breakers or fuses have been installed for the purpose of automatically freeing circuits from arcs, either between line wires or to ground. The principle of operation includes the momentary short-circuiting of the arc by automatic apparatus at some predetermined place, which opens the circuit as soon as the original arc is suppressed. The following reports have been received bearing on such apparatus.

Pa. W. P. We are using the arc suppressor invented and designed by L.C. Nicholson of Buffalo, N. Y. This device consists in a general way of electromagnetic relay switches connected in series with the main transmission line. The overload caused by a flash-over produced by lightning closes these electromagnetic switches rapidly, and in this way short-circuits the wires between which the flash-over is taking place, with a fuse wire calibrated to blow in about 5-10 cycles. This device worked very successfully in 1912 and 1913. It is especially satisfactory when a ground or a short circuit takes place only between two of the transmission wires. In such cases, it saves all of the synchronous load. If a three-phase short-circuit takes place, the effect on the synchronous machinery is more serious. About 50 per cent of the load can, however, be saved, especially if the synchronous converters, of which the main load consists, are separately excited, so as to prevent reversal of polarity.

With the Nicholson arc extinguisher are also connected certain electrostatic relays, intended to work in such a way that when one wire becomes grounded, a switch will be closed, and by this means, a fuse wire, which is timed to blow in about 1/2 second, will be connected between the wire which is grounded, and the ground. This device worked successfully several times. The electrostatic relays which initiate this action seem, however, somewhat less reliable than the magnetic relays, which get into action on short circuits on the line. The electrostatic relays are at present cut out of service, due to the fact that the principle they are based on will make them operate unnecessarily and thus produce undesirable complications whenever the voltage on the line for a moment is lowered artificially by operation of field-destroying device.

In case the arc extinguisher as outlined above does not work, or does not extinguish the arcs, the field is automatically destroyed on all generators in all three power houses connected together, and after $1\frac{1}{2}$ sec. the field is restored again automatically, and, normally a large part of the synchronous load will, in this way, be pulled into step again.

The relays, which in the main power house (Holtwood) actuate the field-destroying and restoring device are either one of the generator relays (in case of short circuit on the line) or the relay in the grounded neutral of one of the transformers connected with the transmission line; these relays act instantaneously themselves, but their action is delayed 4 sec. (by means of a definite time limit relay) in order to give other protective devices their chance. The main difficulty we have experienced with this device is to prevent the generators in the power house (waterwheel-driven) when some of their prime movers were on "hand control" (*i.e.* had a steady gate opening), from speeding up the moment the field was taken off and thus getting decidedly out of synchronism. When originally installed, the time the field was left open (*i.e.* short-circuited with the standard discharge resistance) was 5 sec.; this time element has this year been cut down to 1½ sec. with the results much better in the above respect than formerly, and yet the time is apparently long enough to extinguish lightning arcs on the transmission line. The 1913 record until October 1st, shows that lightning has hit our lines 32 times resulting in three total interruptions, while the trouble was cleared successfully, with little or no loss of load, 18 times by arc extinguisher, 9 times by field-destroying device, and two times by relays opening one of two parallel circuits.

Tor. P. The circuit-breaker type of arc suppressor was tried but was not a success. The Nicholson electromagnetic type is being installed.

Niag. L. & O. P. Uses both Nicholson automatic grounding and Nicholson automatic short-circuiting devices.

LOWERING VOLTAGE TO CLEAR SHORT CIRCUIT (QUESTION E-11)

In reply to question as to whether the voltage of generator is lowered in case of trouble the following were received:

Miss. P. Yes, by hand and automatically.

Gt. Wn. P. Yes, by hand.

Yad. R. P. Yes, by hand.

Sou. S. P. Yes, by hand, expect to install device to automatically lower voltage at time of short circuit or ground on line.

Pa. W. P. See notes under Special Protective Devices (Question E, 1-4 above),

Wash. W. P. No, only when line is on a single generator as a separate system.

Tor. P. Automatically.

San. J. L. & P. No.

Niag. L. & O. P. No.

Port. R. L. & P. On special occasions by hand.

Sou. C. E. Yes, by hand.

Cha. V. R. L. & P. No.

C. N. P. Excitation is from induction-motor-driven d-c. generators. The motors are supplied from busbars fed by the alternators which they excite. In case of a short circuit, exciter sets automatically slow down and reduce field excitation.

Pug. S. T. L. & P. Yes, have auxiliary relay on Tirrill regulator that prevents increase of field strength during short circuit.

Mt. Wh'y P. No.

Un. T. No.

USABILITY OF TELEPHONE LINES (SECTION F)

The conclusions to be drawn from the replies to the questions on telephone lines may be summarized.

In general no company can entirely rely on its telephone line when the power line is grounded and many cannot use their telephones while electrolytic lightning arresters are being charged. The effect of the grounding of the high-tension line is to make it noisy and to cause discharges over arresters and sometimes to cause telephone fuses to blow.

The following comments are noteworthy:

Gt. Wn. P. Most severe trouble is from a ground on the 100,000-volt line. This in general will cause a break over the insulation of the telephone line which is carried on 6600-volt porcelain insulators. To quiet the line, 2-kw. 2200/220-volt transformers used as drainage coils with the secondaries open were installed; these were successful.

Yad. R. P. The telephone line is said to be usable at all times and grounding of the transmission line to have no effect. This telephone line is from 500 ft. to one mile away from power line.

Sou. S. P. Telephone line not always usable. Most of trouble is due to mechanical faults occurring in telephone lines. Induction is also noticed. Arcing on horns of out-of-door switches is quite noticeable on telephone lines. Ground on transmission line makes telephone very noisy.

Pa. W. & P. Users of telephones protected by lightning arresters and fuses on line side of instruments. Insulating transformers used at Baltimore end of telephone line.

Telephone usable practically at all times during operation.

Telephone not usable only at time of ground on transmission line or during charging of electrolytic arresters.

Troubles on transmission line blow fuses or burn arresters on telephone line occasionally. Sometimes burn out telephones.

There has not been much trouble and talking is remarkably good on telephone lines—equally as good as Bell long-distance lines.

Niag. L. & O. P. Heavy induction by grounds on power lines sometimes blows fuses on telephone lines at stations. Telephone is practically always usable due to bleeding coils.

Cty. S. L. Dpt. Induced currents have caused telephone wires spaced 12 in. apart to wrap together. Line disturbances sometimes blow telephone fuses (¼ ampere). We do not attempt to use telephones while a disturbance is on line.

NOTE: The following description of the protective apparatus used by the Georgia Railway and Power Company to shield its telephone line from disturbances on the high-tension transmission line, together with an account of tests made thereon, has been furnished by Mr. E. P. Peck, Ass't. Electrical Engineer.

The telephone line of the Georgia Railway & Power Company from Atlanta to Tallulah Falls, a distance of 87 miles, has No. 4 bi-metallic conductors, insulated with single disk suspension insulators. These insulators have a dry flash-over test of 70,000 volts but it is the purpose of the company to connect two of them in series on the telephone line at the earliest possible date. The telephone line is strung on the main 110,000-volt tower line, about 10½ ft. from the lower power conductor.

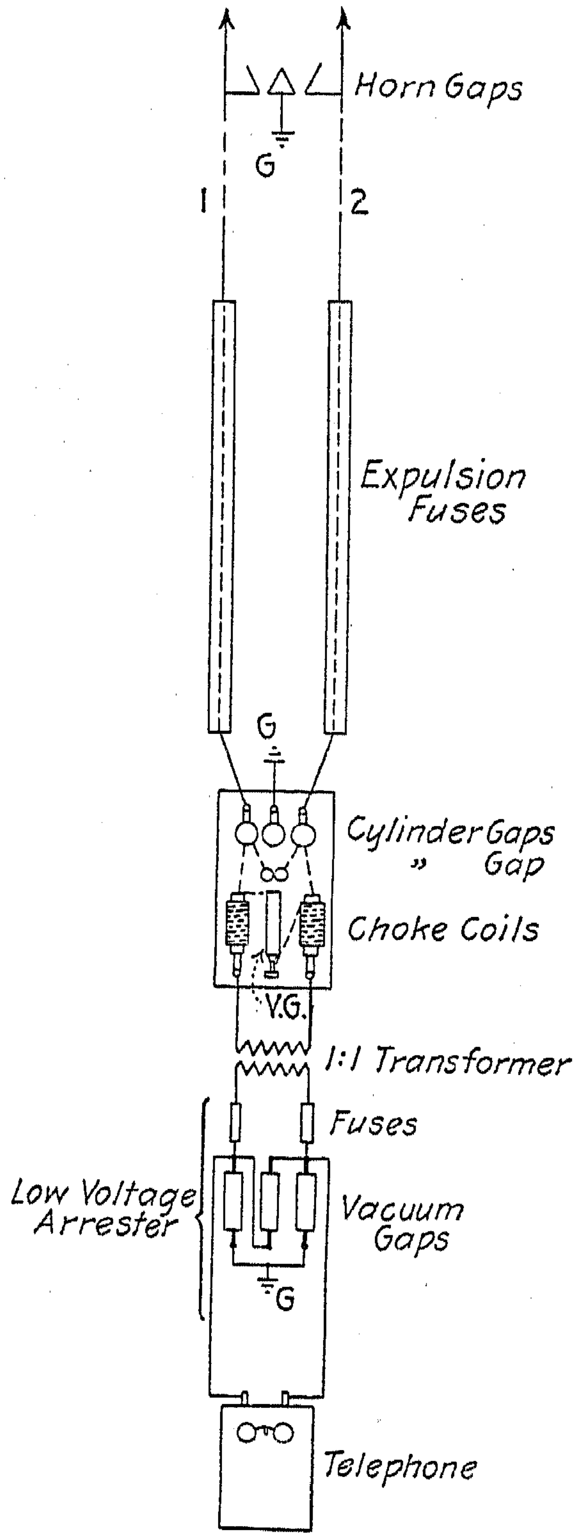
The telephone line operates at a voltage to ground of approximately 5300 volts, when no drainage coils are connected. The voltage from line to line is very low, except in cases of insulation troubles on the main power line or on the telephone line.

Trouble was experienced, due to the high voltage on the telephone line, and to remedy this, drainage coils have been connected at the Boulevard substation in Atlanta and at Gainesville substation. A drainage coil will be connected at the power house also, in a short time. A standard 15-kw., 2200-volt power transformer is used as a drainage coil. The 2200-volt leads of the transformer are connected to the line wires and the middle tap of the primary is connected to ground, the secondaries being left open.

With the drainage coils connected in Gainesville and in Atlanta, the voltage from the telephone line to ground is approximately forty-five volts, the drainage coils carrying a current of approximately 3.75 amperes, continuously, in the ground leg.

The telephones in all of the stations are connected to the telephone line through telephone transformers, insulated for 25,000 volts from primary to secondary.

A number of telephone transformers and telephones have been damaged on this line, the damage resulting from lightning along the line or from leakage either on the main power system or on the telephone line. To stop the telephone and telephone transformer trouble, a lightning arrester has been developed which gives promise of excellent results. The apparatus (diagram of connections shown herewith) consists of proper relief gaps which are protected by expulsion fuses. The most important part of this arrester unit is a vacuum gap adjusted to break down at approximately 350 volts and connected from line to line. Adjustable cylinder gaps are connected from each line to ground and other cylinder gaps are connected in parallel with the vacuum gap. Choke coils, wound on porcelain cores and with turns very heavily insulated, are connected between the gaps and the telephone.



The action of the arrester in case of high voltage on the telephone line is as follows: A high voltage impulse being impressed on the lines equally, will raise the voltage of the telephone line and telephone transformer to a value sufficient to break down the air gap to ground and will not impress any high voltage across the terminals of the telephone transformer unless the ground gaps are set unequally, in which case the gap with the smallest setting will drain the wire connected to it directly and will drain the wire with the larger gap setting through the vacuum tube arrester.

If the voltage is impressed unequally on the telephone lines, the vacuum gap will spark across, holding the voltage across the terminals of the telephone transformer and the telephone to a safe, low value.

The choke coils are used to retard steep wave front impulses until the arrester gaps will have time to discharge.

It has been found that a continuous discharge through the vacuum gap will melt the solder and compound used to seal the case of the vacuum tube, allowing the vacuum to be destroyed. The cylinder gap connected in parallel with the vacuum gap is for the purpose of holding the line-to-line voltage as low as possible in case the vacuum gap is destroyed. The lowest advisable setting on these cylinders will give an arcing voltage in the air of approximately 700 volts and the cylinder gap will never come into play unless the vacuum gap has been destroyed.

The expulsion fuses used are of five-ampere capacity and will not blow unless there is a very severe disturbance on the telephone line. The five-ampere fuse was selected because we did not wish to use a fuse large enough to cause burning of the vacuum gap or the cylinder gaps or to use a fuse so small that it would blow on slight disturbances.

A test was made on this lightning arrester by taking 50,000 volts from a power line supplied from a 550-kw. generator, the power line being connected from line to line on the telephone arrester, from each line to ground and both lines in parallel to ground. Eight tests were made on one arrester with this 50,000-volt power supply, with a telephone transformer and telephone connected during the tests.

Tests were also made in the lightning arrester laboratory of the General Electric Company on oscillation transformers of 200,000 and 500,000 cycles with oscillating circuits adjusted for voltages from 50,000 to 150,000 volts. An arrester unit was connected in parallel and in series with the main sphere gaps and a number of shots were made. After the completion of the tests the telephone transformer and telephone were still in good condition.

A number of small arresters with the same essential arrangement of the arrester parts have been used on telephone lines paralleling 11,000- and 22,000-volt lines around Atlanta. Some of these arresters have seen about two years' service.

A large number of severe lightning disturbances have been handled by these arresters and in one case the 22,000-volt power line fell on the telephone line immediately after the lightning stroke. The main wires to the arrester and the ground wires on the arresters at both ends of the lines were burned off and in this case as well as in all other cases no damage has been done to the telephone transformer or to the telephone. In the same territory a very large number of telephone transformers and telephones have been destroyed by lightning although they were protected by the best arrester system which we had been able to obtain rom the manufacturers.

TEST OF TELEPHONE LIGHTNING ARRESTER TO BE USED ON TELEPHONE LINES ADJACENT TO 110,000-VOLT POWER LINES

One 555-kw., 440-volt, 60-cycle alternator was connected to a 625-kw., 440 to 50,000-volt transformer and the high side of the transformer used on the arrester tests. On these tests the circuit breaker of the transformer bank was set at 1600 amperes, the normal load on one generator being 625 amperes.

Test No. 1. Referring to the diagram on a preceding page, the horn gaps at the top were not used.

Line No. 1 was connected to one transformer terminal and line No. 2 was connected to the other transformer terminal. The generator was adjusted to give 50,000 volts and the circuit breaker closed, giving 50,000 volts directly on the telephone lightning arrester. On this test the cylinder gaps and the vacuum gap on the main line arced across, blowing the main line fuses.

Test No. 2. Same as test No. 1.

Test No. 3. Lines No. 1 and No. 2 were tied together and connected to one power transformer terminal and the leads marked ground were connected to the other transformer terminal. When 50,000 volts was applied the spark gaps arced across, blowing the primary fuses.

Test No. 4. Same as No. 3.

Tests No. 5 and No. 6. Line No. 2 was connected to one power transformer terminal, and ground gap connected to the other power transformer terminal. 50,000 volts was applied, blowing the primary fuses.

Tests No. 7 and No. 8. Line No. 1 was connected to one power transformer terminal, and the ground gap connected to the other power transformer terminal. 50,000 volts was applied, blowing the primary fuses.

After each of the above tests the 1 to 1 transformer and the telephone bell were tested and found OK. The vacuum gap connected on the high side of the 1 to 1 transformer broke down at 360 volts before the high-voltage tests were made, and broke down at 370 volts after tests were made.

It is of interest to note that the arrester on the low side of the telephone transformer never had its fuses blown, showing that all high-voltage strains were relieved before they reached the telephone transformer.

This test corresponds very closely to the condition which will obtain when one of the 110,000-volt power lines crosses with either or both of the telephone lines. In this case the voltage will be 63,500 volts, while the voltage on the tests was 50,000. However, in service, 63,500 volts can never reach the telephone lightning arrester because the insulators on the telephone line will arc across at much lower voltage than this.

PRESERVATIVES FOR WOOD CONSTRUCTION (QUESTIONS G-1-2)

The following information is received as to preservative treatment of wood poles:

The following companies treat wooden pole butts—either by brushing or open tank treatment using carbolineum, hot gas drippings, creosote oil, or hot tar.

Miss. P. (cost 10 cents per pole), for brush treatment only.

Gt. Wn. P.

Ap. P.

Sou. S. P. Open tank process.

Wash. W. P. Carbolineum oil on cedar poles; two feet above and below ground line. Tamarack poles treated by charring 6 ft. below ground line and pouring hot carbolineum oil over charred surface. Cost 25 cents per pole.

San J. L. & P. Open tank process; average penetration 5/8 in. for 8 ft. on butt; cost approx. $1.50 per 50-ft. pole.

Niag. L. & O. P.

Ch'a V. R. L. & P. Open tank; cost 40 cents to $1.50.

Ut. L. & R. Cost one quart carbolineum and 10 cents labor per pole.

Mt. Wh. P. & E. Paint poles; cost 50 cents per pole.

Un. T.

TREATING CROSSARMS (QUESTIONS G-3-4)

The following companies treat crossarms and pins as specified:

Yad. R. P. Crossarms and pins, open tank, four hours in oil 100 deg. cent. 4 hours in cold oil.

Ap. P. Crossarms same as butts.

Sou. S. P. Crossarms and pins same as butts.

San J. L. & P. Crossarms given two coats of good paint.

Niag. L. & O. P. Crossarms creosoted in open tanks or treated with avenarius carbolineum.

Port. R. L. & P. Crossarms dipped in preservative.

Ch'a V. R. L. & P. Crossarms brush treated.

Ut. L. & R. Crossarms, paint and oil; pins paraffin.

C. N. P. Pins on new line impregnated with bakelite.

Mt. Wh. P. & E. Pins boiled in linseed oil.

Un. T. Crossarms and pins—open tank creosote treatment.

Cty. S. L. Dpt. Boiled in carbolineum.

GAIN IN LIFE BY TREATMENT (QUESTION G-5)

With regard to the gain in life from treatment note the following:

Gt. Wn. P. No deterioration as yet.

Sou. S. P. 5 to 10 years, based on older Colorado-Nevada Power Co. System.

San. J. L. & P. Creosoted butts have lasted 6 years on pine poles, that would otherwise decay in 16 months. We have only been treating pole butts for 6 years, but our experience shows the protection afforded is well worth the cost. Our principal pole timber is Washington red cedar.

By creosoting butts and properly painting crossarms, the wooden pole line should have a life of at least 25 years. We have a square sawed redwood line, carrying six No. 3 copper conductors at 30,000 volts (and a portion of the time 60,000 volts), 35 miles long. This was built 8 years ago and pole butts were *not* treated. Recent patrol and inspection showed 70 per cent of poles perfectly sound above and below ground.

Niag. L. & O. P. Crossarms in good condition; poles show various amounts of decay at ground line.

Port. R. L. & P. Poles last 12 to 15 years without treatment and under favorable conditions treatment may add two or three years to life of pole.

Ch'a V. R. L. & P. Life of poles has been increased.

Ut. L. & R. 10 years in dry climate.

Cty S. L. Dpt. Crossarms 12 years old show no depreciation.

OUTDOOR OIL APPARATUS (QUESTION H-4)

As to the general satisfaction with outdoor transformers, oil switches and substations, note the following:

Miss. P. Satisfactory.

Yad. R. P. Satisfactory, are using them exclusively in high-tension work.

Ap. P. Yes.

Sou. S. P. Outdoor stations on transmission line serve as switching stations as well as transforming stations. Two switches are cut into each of these two lines passing through the station and a paralleling set of disconnecting switches for lines. Steel is used throughout for the supporting structures. Transformers are all provided with trucks and each station has a transfer track and truck for moving transformers into a building which contains a pit and lifting rig and also serves as a storeroom for supplies and repairs. We have every reason to be pleased with the outdoor type station of this character.

Wash. W. P. Cheaper and satisfactory.

San J. L. & P. We place station transformers on separate foundations, about 35 ft. apart. Poles are placed directly back of each transformer, to which are attached, by strain insulators, the high-tension and low-tension leads to the switch house. The switching house protects both high-tension and low-tension switches and metering equipment. This house is usually a frame structure covered with galvanized iron. Current transformers are installed indoors and potential transformers on poles outside. These stations have proved very satisfactory.

Niag. L. & O. P. Westinghouse outdoor type GA, oil circuit breaker satisfactory.

Ch'a V. R. L. & P. All standard and entirely satisfactory.

Mt. Wh'y P. & E. Yes.

Cty. S. L. Dpt. Outdoor bushings all right on electrolytic lightning arresters.

USE OF BREATHERS (QUESTION H-5)

Most companies report that they do not use breathers in outdoor transformers but the following may be noted:

Yad. R. P. Use chloride of lime breathers but do not consider them necessary.

Mt. Wh'y P. & E. Yes, no trouble so far—use inverted elbow and fine mesh screen.

PENETRATION OF WATER IN OUTDOOR TRANSFORMERS (QUESTION H-6)

Most companies report that no water penetrated weatherproof tanks, but note—

Yad. R. P. Not when in operation and temperature high.

San J. L. & P. In some of smaller sizes of transformers (100 kw.) moisture has penetrated the tanks. However, other installations of exactly similar make and capacity gave no trouble.

OUTDOOR TYPE HIGH-TENSION BUSHINGS IN WET WEATHER (QUESTION H-7)

Most companies report that outdoor type bushings operate satisfactorily in wet weather and none report trouble.

CORONA (QUESTION H-13)

No plant has observed any corona except *Miss. P.*, which gave a curve of corona losses reproduced in the drawing, Fig. 57.

GENERAL

Pa. W. & P. Note the following general comments:

Some of the changes which we have made, or contemplate making, in our equipment may be of interest as indicating the lines along which our operating experience and experiments are leading us.

A duplicate 11,000-volt generating station bus system was installed to replace the original group single bus system. This change made it easier to inspect and clean buses and connections, and made possible a better grouping of apparatus and reactances to limit short-circuit rush of current.

Reactances were installed between buses and transformers, and in sections of the buses. These reactances were rendered necessary by reason of the concentration of generating apparatus, giving peaks of over 70,000 kw., all of which power was sent over two transmission circuits to Baltimore. The destructive effects of short circuits backed by such large generator capacity were becoming serious.

Nicholson arresters and field-destroying devices were installed and a *fused air gap* arranged for the generating station to take a portion of these *heavy lightning discharges* which are *too great* for the *electrolytic arresters* to take care of. The Tirrill regulator equipment was abandoned and a storage battery with Keilholtz-Ricketts booster regulating system installed.

During the first period of operation the relay system was based upon the use of inverse time-element, reverse power, and definite time-element relays, set progressively higher in time from substation to power house. A great deal of experimental work, both in the laboratory and under operating conditions, was done in connection with the development of more accurate relays, but the results were not satisfactory. For a time, a modified Mertz-Price system was considered and partially installed, but was later abandoned for the system at present in use, which gives immensely superior results over the previous systems. With a steady increase of generator capacity concentrated on a few circuits, the destructive effects of arcs are becoming greater, so that a short circuit, which previously, with a small generator capacity, could have been allowed to remain on for six or seven seconds, now does too much damage in that time in the way of melting of conductors, etc., so that our experiments are now along the line of cutting down the length of time which a short circuit remains upon the system.

We attribute our freedom from sleet disturbances to the very heavy mechanical construction employed and the frequent spacing of anchor towers.

We are now building a second tower line to Baltimore on the same 100 ft. right of way strip, 50 ft. distant from the first tower line. The second tower line has the following improvements: the number of members to a tower is less than previously, decreasing handling, erection and inspection costs, and making possible a minimum thickness of material of 3/16 in. as against a previous minimum of 1/8 in. All bolts are 5/8 in. diameter as against ½ in. diameter for the previous towers; the smaller bolts are very likely to be overstressed in tightening. The middle crossarm of the new line is being lengthened so that the top and bottom conductors of a circuit will be in the same vertical plane while the middle conductor will be further away from the tower.

This is to take care of unequal sags due to unequal sleet loading. Such unequal sleet loading has actually been observed on our lines and was anticipated in the design of the first line, but so far the unequal loading has not been sufficient to interfere with service. The distance between the crossarm and the conductor just above was such that on the old line buzzards when raising their wings to fly would ground the circuit; in the new line, a greater distance between crossarm and conductor above has been arranged for. In the first line steel tripod foundation stubs were used for the suspension towers; in the new line, all foundation stubs are of concrete. Interchangeability of bolts and certain members has been provided for in the new towers, which makes easier work of erection of the towers in the way of distribution of material and assembly.

In the first line as originally built there was a very considerable arcing over of the insulators due to lightning. A very complete record was kept covering the location of the disturbances, the phases upon which disturbances occurred, insulators cracked, etc. During the following year additional insulator units were added on one circuit over those two sections of the transmission line which had suffered most the previous year and a careful record again kept of the effect of lightning. These records indicated that there were no spill-overs during the second year on those sections where additional insulator units had been cut in, except in one case where the discharge had jumped from conductor to crossarm below; this clearance distance having been decreased by the additional insulator units. Then additional strain and suspension insulator units were cut in on both circuits, so that at present No. 1 circuit has seven instead of five insulator units and eight instead of six strain units. Circuit No. 2 has six instead of five insulator units and seven instead of six strain units. The improvement, as regards lessened lightning spill overs, during the time the more heavily reinforced lines have been in service, has been marked.

The first transmission line was equipped with a single ground wire. Our experience has not indicated that this ground wire has been of any benefit in preventing disturbances. In order to establish the matter a little more definitely, the new transmission line is being equipped with two ground wires placed above and outside of the upper power conductors. The ground wire on the first line was originally strung so tight as to cause considerable trembling of the towers and it was necessary to cut in additional ground wire to increase the ground wire sag. This was done during operation without interfering with service.

DRAWINGS

The following cuts are reproduced from drawings, charts and photographs submitted by the various reporting companies. In most cases the drawings have been redrawn to eliminate unnecessary detail and to consolidate the useful information embodied. The significance of each drawing may be obtained from its title, combined with the legends or other information on the face of the drawing. In all cases except one the name of the company furnishing the information is noted.

A number of valuable maps, charts, and photographs were received which could not be readily reproduced. These are open to the inspection of members of the Institute at New York headquarters. The Secretary will, where feasible, furnish copies for cost* on application. A list of some of the more valuable matter not reproduced follows:

Geographical Maps. Gt. Wn. P.; Yad. R. P.; Mex. L. & P., Ap.. P.; Sou. S. P.; Niag. L. & O. P.; Port. R. L. & P.; Mt. Wh'y P. & E.; X.

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*In case of blue-prints retracing will generally be necessary.

Line Circuit Diagrams. *Mex. L. & P.; *Pa. W. & P.; *Niag. L. & O. P.; W'n St's. G. & E.; C. N. P.; Mt. Wh'y P. & E.; *Pug. S. T. L. & P.

Design Drawings of Steel Towers with Details. Miss. R. P.; Yad. R. P.; Niag. L. & O. P. (pipe towers); C. N. P. (pipe towers).

Detail Drawings of Wood Pole Construction. Niag. L. & O. P. (pin details of A-frame top); Wash. W. P. (two-pole braced "bridge" construction, 2 types one circuit line with one ground wire, 2 types one circuit line with no ground wire, angle towers with grounded wire guards); also W'n St's G. & E.; Pug. S. T. L. & P., (A-frame pole and pole-top switch); and X.

Miss. R. P. Tower foundation drawing.

Wash. W. P. Details of telephone line transposition. Detail of cable clamps and usual attachments for suspension insulators; wrought iron pin; details of extension of middle crossarm on steel towers added after erection.

Port. R. L. & P. Details of "jumper" at strain pole and insulator attachment; detail of outlet and the first span of the line at power house.

Niag. L. & O. P. Detail arrangement of room with transformers, electrolytic arresters and wiring.

Mt. Wh'y P. & E. Details of 33,000- and 6600-volt telephone and railway crossing.

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*Showing sectionalizing of busbars, types and locations of circuit breakers, etc.

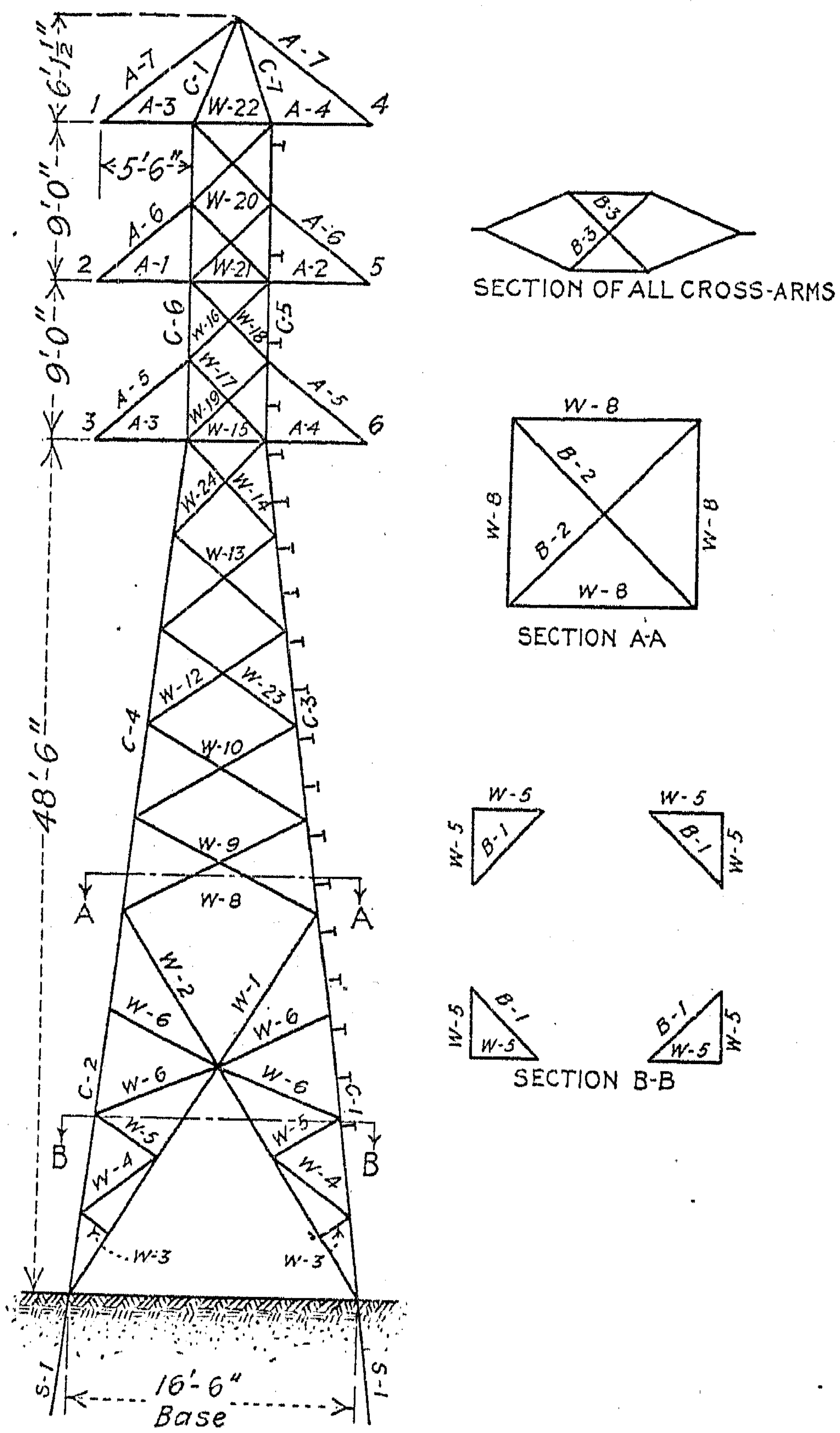


Fig. 1—Yakdin River Power Co.—Standard Double Circuit Transmission Tower for 100-Kv. Lines

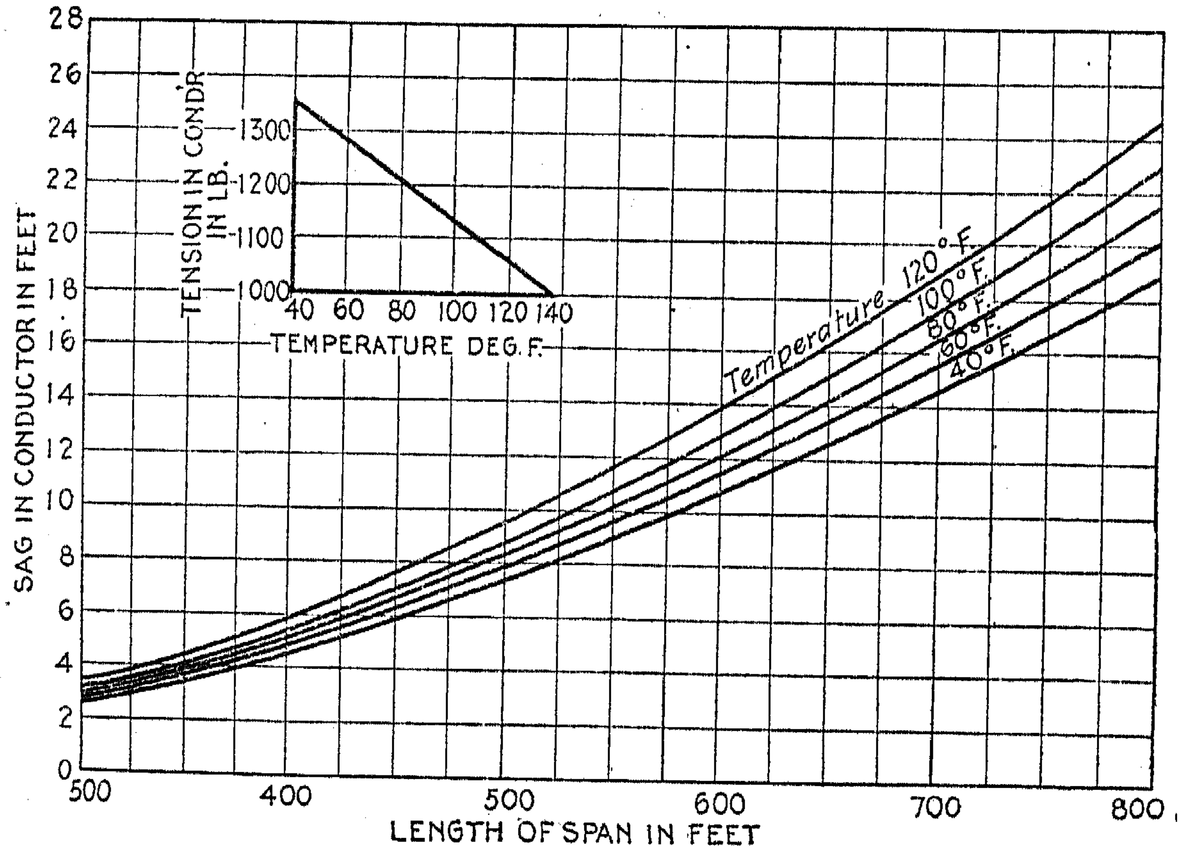


Fig. 2—Yadkin River Power Co.—Sag and Tension Curves for No. O. B. & S. Copper Strand.

Note:—Maximum strain 25,000 lb. per sq. in. at 0 deg. fahr., ¼ in. sleet, 50 mi. per hr. wind

LIST OF MATERIAL FOR ONE COMPLETE TOWER. (See Fig 1).

No.	Shape	Size	Length		Mark	Remarks	Weight in Lb.
			Ft.	In.			
1	L	3 x 3 x 3/16"	27–	8 5/16	C-1		102.7
3	L^5	3 x 3 x 3/16	27–	8 5/16	C-2		308.2
1	L	2¾ x 2¾ x 3-16	21–	10	C-3		74.0
3	L^5	2¾ x 2¾ x 3-16	21–	10	C-4		222.0
1	L	2½ x 2½ x 1/8	18–	8 3/16	C-5		38.8
3	L^5	2½ x 2½ x 1/8	18–	8 3/16	C-6		116.6
4	L^5	2½ x 2½ x 1/8	6–	8 1/8	C-7		55.6
2	L^5	2½ x 2½ x 1/8	6–	4½	A-1		26.5
2	L^5	2½ x 2½ x 1/8	6–	4½	A-2		26.5
4	L^5	2½ x 2½ x 1/8	6–	4½	A-3		53.0
4	L^5	2½ x 2½ x 1/8	6–	4½	A-4		53.0
4	Flats	1¼ x 3/16	7–	5 9/16	A-5		23.8
4	Flats	1¼ x 3/16	7–	6 3/8	A-6		24.0
4	Flats	1¼ x 3/16	9–	4¾	A-7		30.0
6	T^5	4½ x 3 x 8.4	0	5 3/16	A-8		21.8
4	L^5	1½ x 1½ x 1/8	25	5 7/8	W-1		125.4
4	L^5	1½ x 1½ x 1/8	25	5 7/8	W-2		125.4
8	L^5	1¼ x 1¼ x 1/8	2	4½	W-3		19.2
8	L^5	1¼ x 1¼ x 1/8	5	7 3/8	W-4		45.3
8	L^5	1¼ x 1¼ x 1/8	4	8 3/8	W-5		37.9
16	L^5	1¼ x 1¼ x 1/8	7	0 3/8	W-6		113.6
4	L^5	2¾ x 2¾ x 1/8	10	11¾	W-8		100.5
8	L^5	1½ x 1½ x 1/8	11	8 9/16	W-9		115.2
8	L^5	1½ x 1½ x 1/8	10	3 15/16	W-10		101.6
4	L^5	1½ x 1½ x 1/8	9	4 9/16	W-11		46.1
2	L^5	2½ x 2½ x 3/16	9	4 9/16	W-12		57.6
8	L^5	1½ x 1½ x 1/8	8	4 1/16	W-13		82.0
6	L^5	1¾ x 1¾ x 1/8	7	4 5/8	W-14		63.8
4	L^5	2 x 2 x 1/8	4	5	W-15		29.1
4	L^5	1¾ x 1¾ x 1/8	6	2 31/32	W-16		36.0
4	L^5	1¾ x 1¾ x 1/8	6	2 31/32	W-17		36.0
4	L^5	1¾ x 1¾ x 1/8	6	2 31/32	W-18		36.0
4	L^5	1¾ x 1¾ x 1/8	6	2 31/32	W-19		36.0
16	L^5	1¼ x 1¼ x 1/8	6	2 1/8	W-20		99.8
2	L^5	2 x 2 x 1/8	4	5	W-21		14.6
2	L^5	2 x 2 x 1/8	4	5	W-22		14.6
4	L^5	1½ x 1½ x 1/8	4	3¾	W-23		21.2
4	L^5	1¼ x 1¼ x 1/8	6	1½	B-1		24.7
2	Flats	1¼ x 3/16	15	8 9/16	B-2		24.9
6	Flats	1¼ x 3/16	6	2¾	B- 3		29.8
38	B. H. St	ep Blts ½" φ	0	5 1/8	Hex. Nu	t 1¾"Thrd.	16.9
38	Pieces ½"	φ Gas Pipe.	0	4	Ends Sq	uare	10.6
38	Washers	1 3/8" φ	9/16"	φ Hole	No. 12 G	age	1.9
390	Bolts ½"	φ 1½" Lnd.	¼"	Min. Gr	ip Sq. Hd	. Hex. Nut.	6.8
4	Bolts ½"	φ 2"	Lng.	7/8 M	in. Grip	Sq. Hd. He	x Nut .9
1	Ground	Wire Clamp					7.4
2	L^5	1¾ x 1¾ x 1/8	7	4 5/8	W-24		21.3
2	L^5	2½ x 2½ x 3/16	9	4 9/16	W-25		57.6
6	Insulator	Hooks					8.7
		Total	Net W	eight of	one Stan	dard Tower	2814.9
4	L^5	3 x 3 x ¼"	8	0	S-1		156.8
4	C^5	12"–20½"	1	6	S-2		123.0
8	Pls.	8 x ½	0	2	S-3		16.4
						Grand Tot	al 3111.1

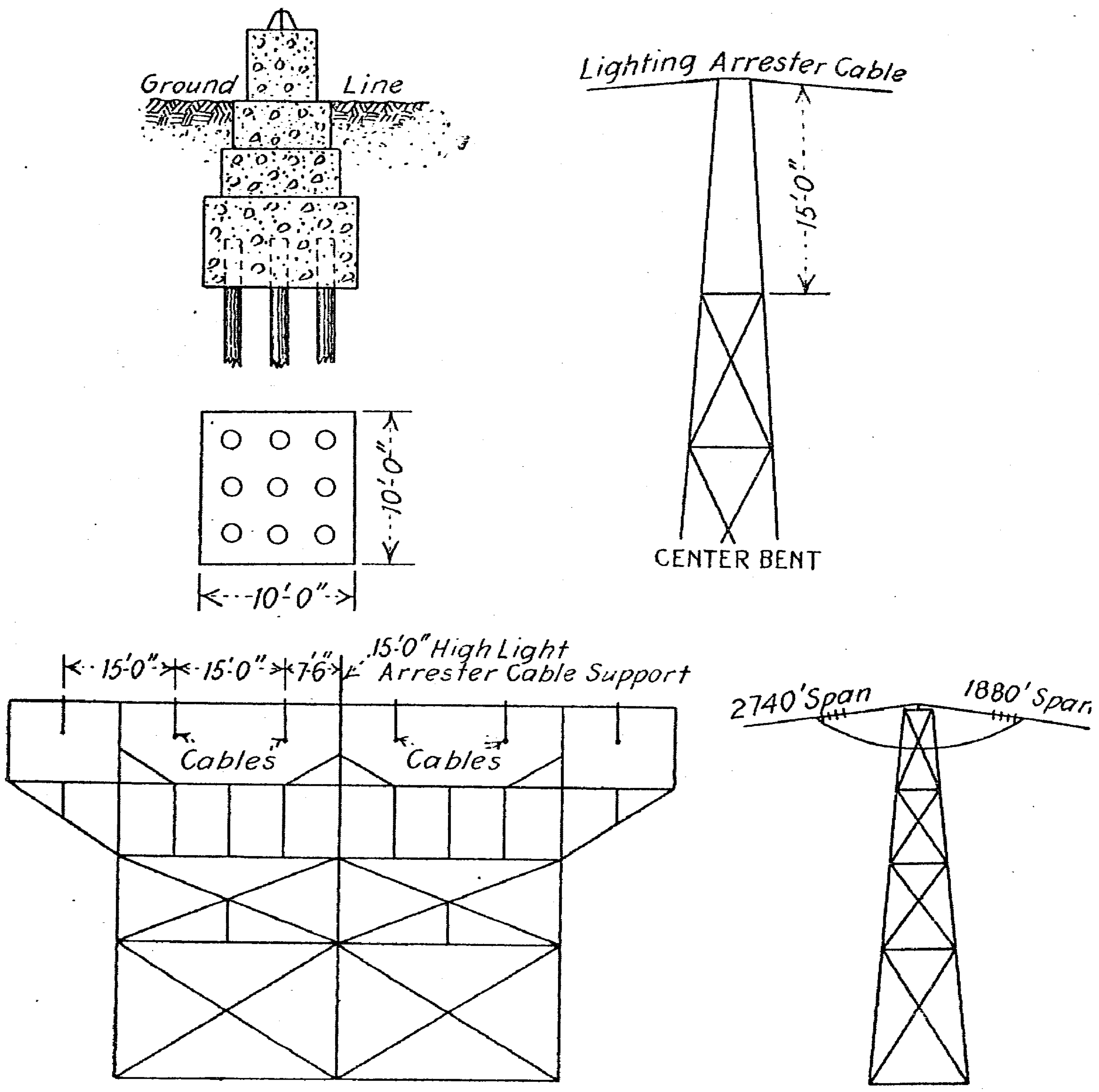


FIG. 3—GREAT WESTERN POWER CO.—TOP OF SPECIAL TOWER AT WEST ISLAND

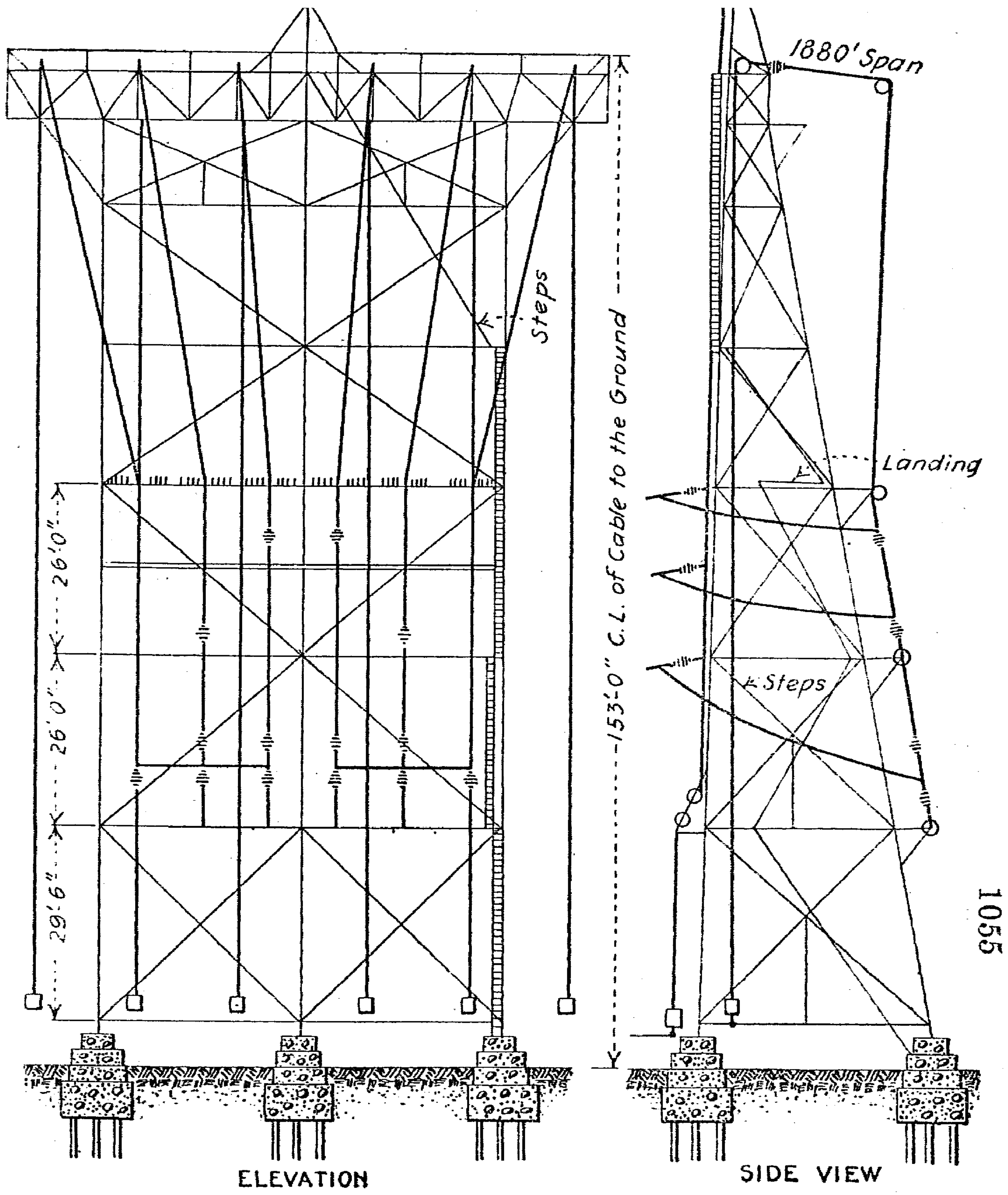


FIG. 4—GREAT WESTERN POWER CO.—SPECIAL TOWER AT KELLY ISLAND

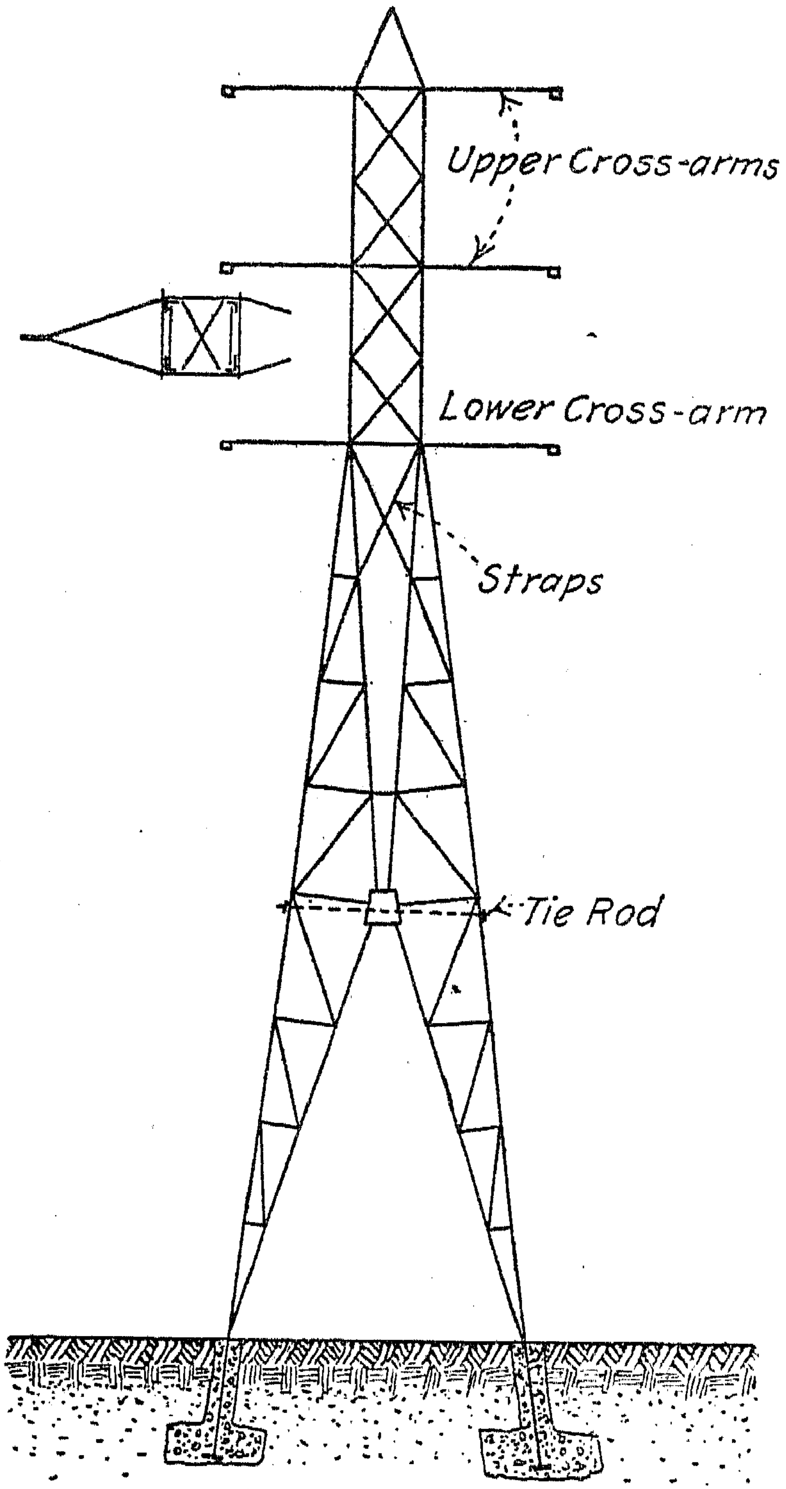


FIG. 5—GREAT WESTERN POWER CO.—SKETCH OF STANDARD TOWER

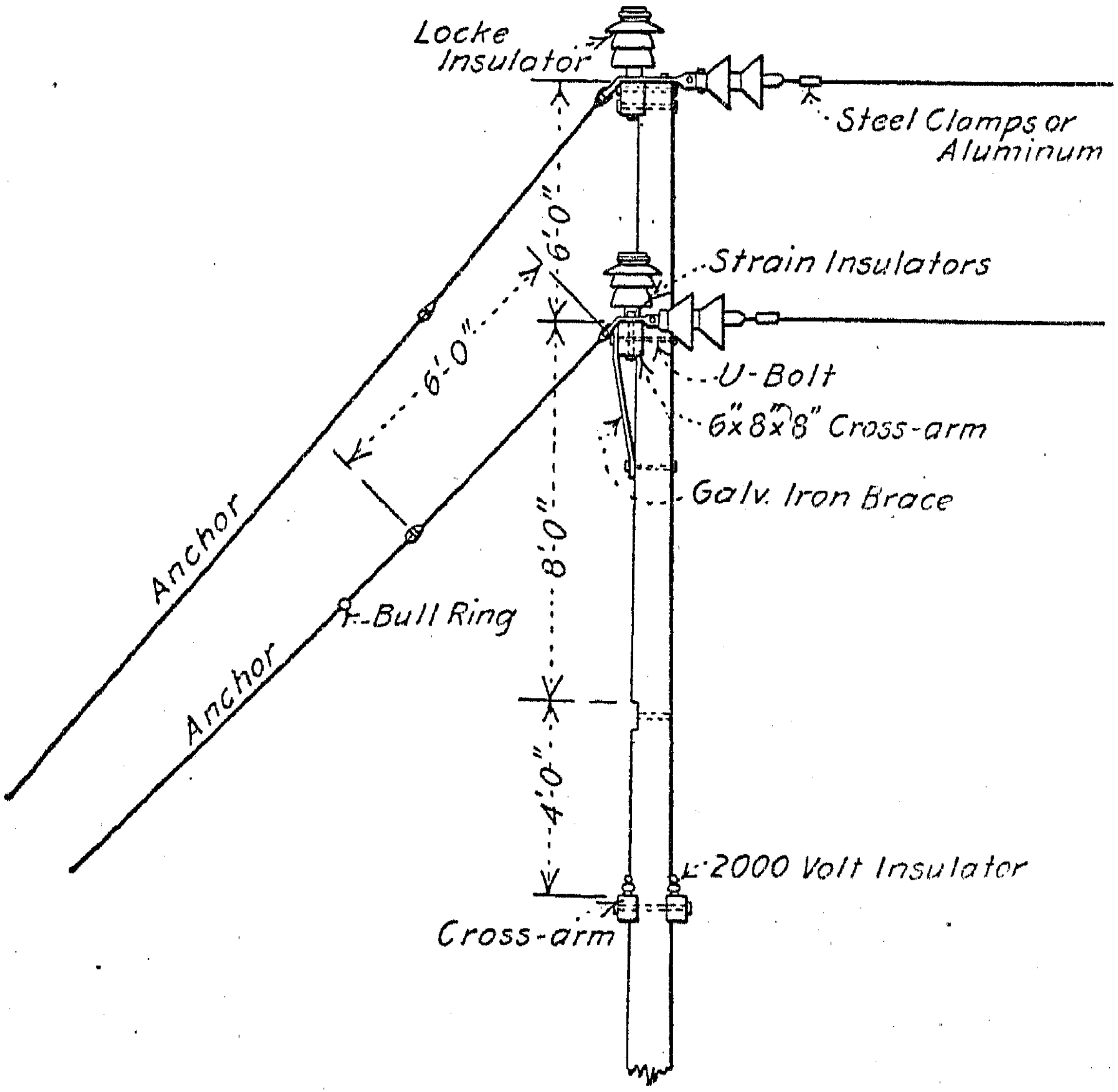


FIG. 6—SAN JOAQUIN LIGHT AND POWER CORPORATION. DETAILS OF ANCHORED POLE

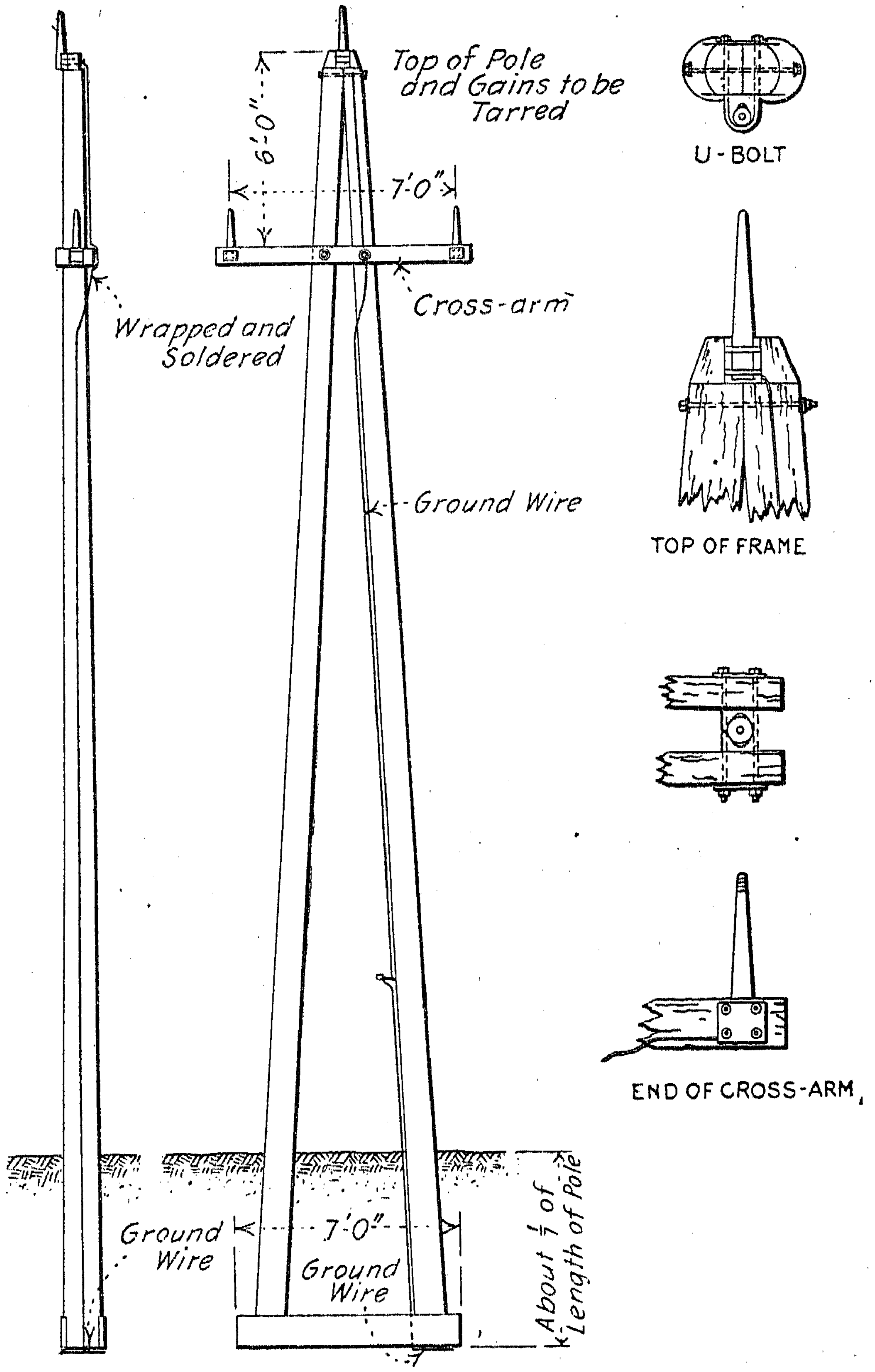


FIG 7—NIAGARA, LOCKPORT AND ONTARIO POWER COMPANY. STANDARD A-FRAME STRUCTURE.

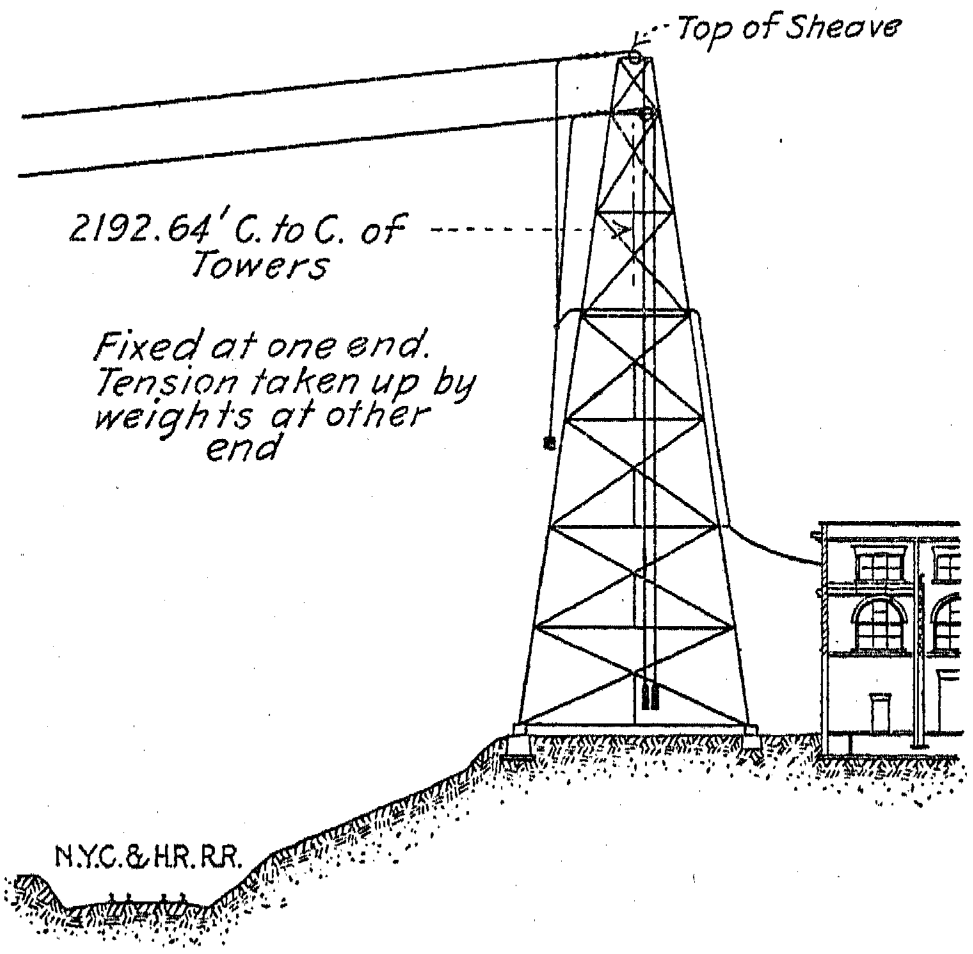

Top of Sheave
2192.64' C. to C. of Towers
Fixed at one end. Tension taken up by weights at other end
N.Y.C.& H.R.R.R.

FIG. 8—CANADIAN NIAGARA POWER CO. TOWER AT NIAGARA CROSSING

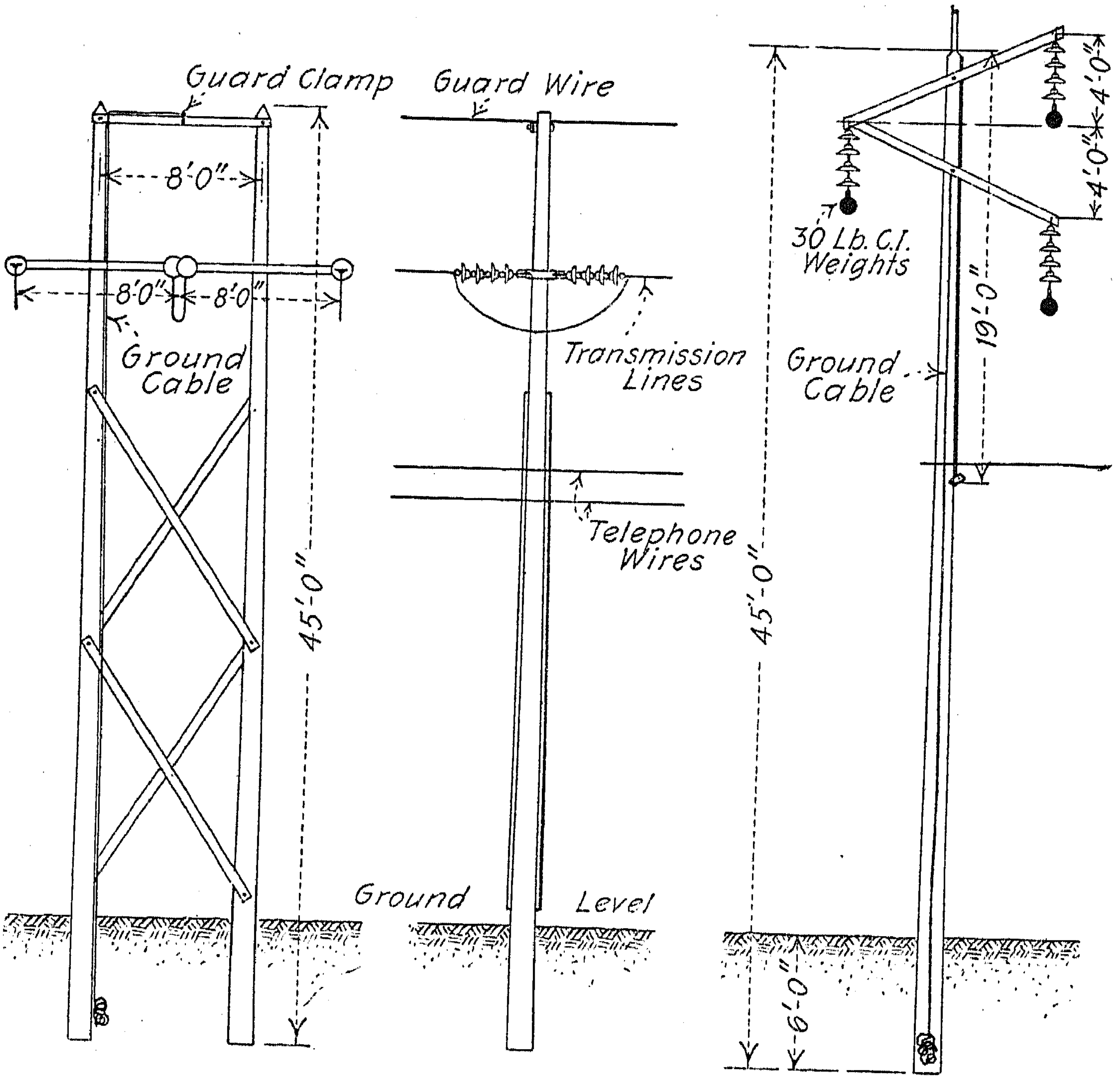
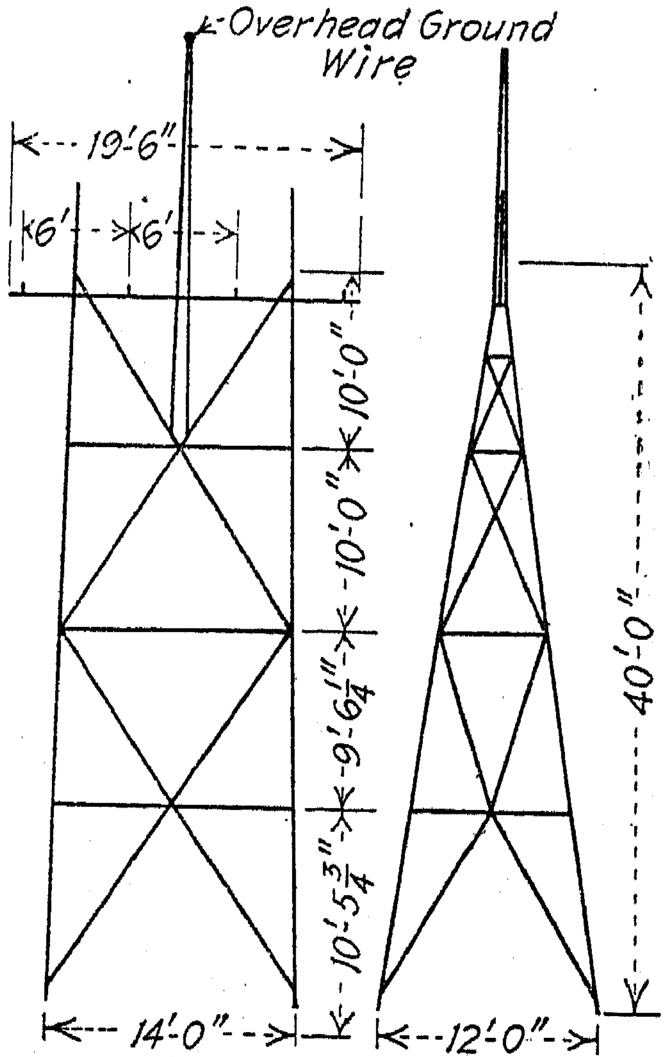
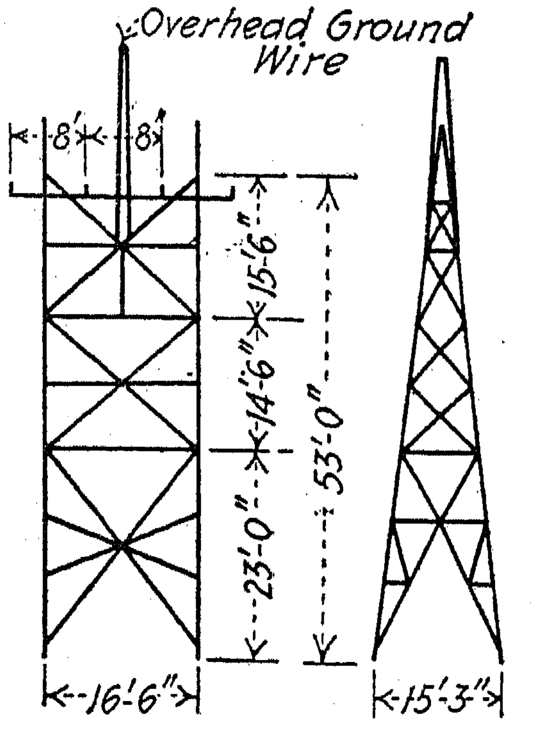


FIG. 9—APPALACHIAN POWER CO. POLE LINE CONSTRUCTION STANDARDS



Std 40 ft. Tower. Present Line. Span-400 ft.

FIG 10—TORONTO POWER CO.



Std. 53 ft. Tower New Line. for 650 ft. Span

FIG. 11—TORONTO POWER CO.

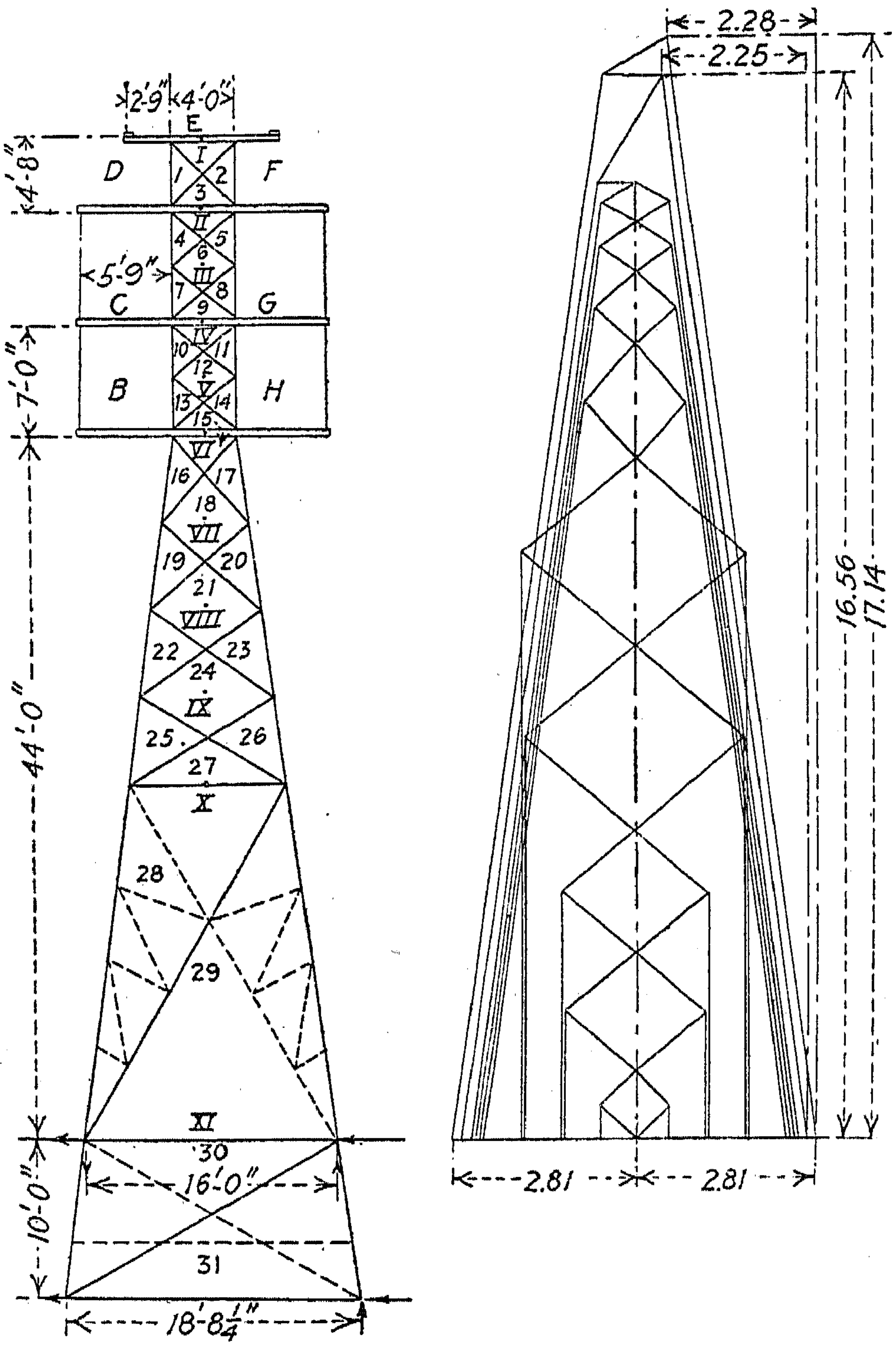


FIG. 12—PENNSYLVANIA WATER AND POWER CO. DETAILS OF TOWER.

	Load from wire	Wind pressure	Total Load
I	1.9	0.22	2.12
II	1.9	0.43	2.33
III		0.14	0.14
IV	1.9	0.42	2.32
V		0.14	0.14
VI	1.9	0.47	2.37
VII		0.22	0.22
VIII		0.23	0.23
IX		0.25	0.25
X		0.49	0.49
XI		0.64	0.64

Wind pressure =13 lb. per sq. foot.

Location	Load	Load per. sq. inch.	Section	Area	Ultimate Strength	Factor of Safety
H–11	6.28	5.65	3″ x 3″ x 3/16″	1.11	39.86	7.
H–14	9.15	8.25	" " "	"	"	4¾″
I–20	14.08	5.85	4″ x 4″ x 5/16″	2.41	35.92	6
I–23	15.04	6.25	" " "	"	"	5¾
I–26	15.94	6.62	" " "	"	"	5½
I–29	10.2	6.36	4″ x 4″ x 3/8″	2.86	35.51	5½
15–17	1.18	2.36	2″ x 2″ x ⅛″	.50	13.27	5⅓
18–20	.85	6.70	" " "	.50	10.92	6½
21–23	.69	.38	" " "	.50	9.00	6⅓
24–26	.60	1.20	" " "	.50	5.85	5
I–31	19.15	6.70	4″ x 4″ x 3/8	2.86	32.51	5

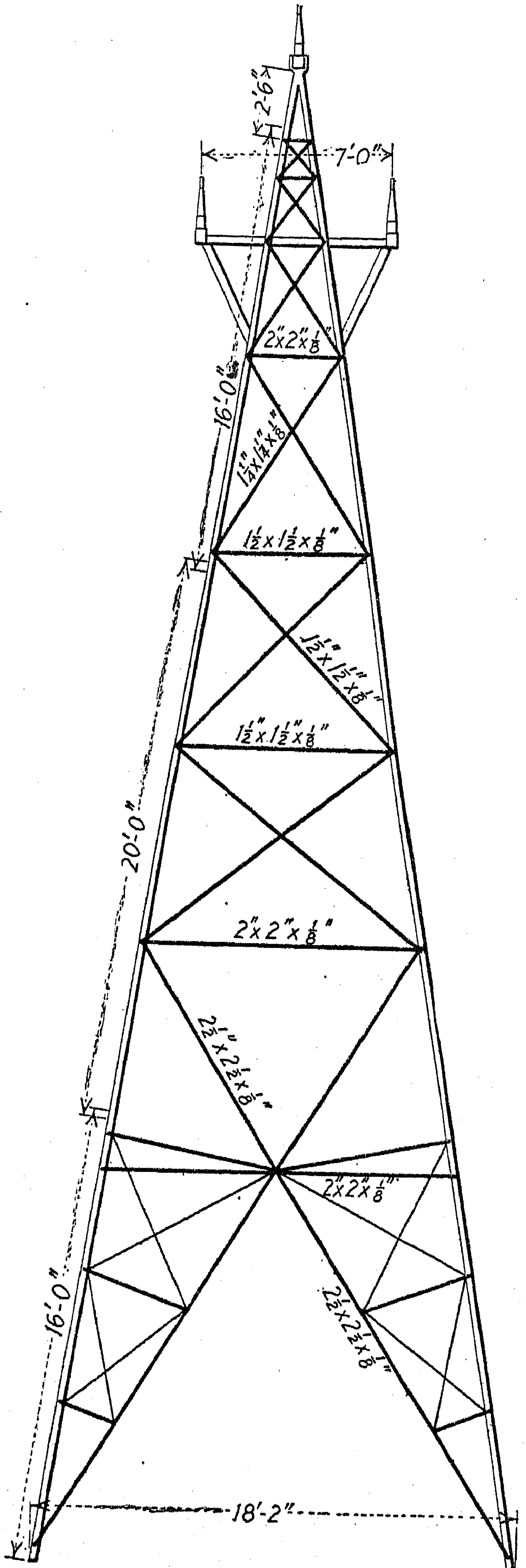


FIG. 13—NIAGARA, LOCKPORT AND ONTARIO POWER CO. 49-FOOT SINGLE AND DOUBLE PIN TOWER

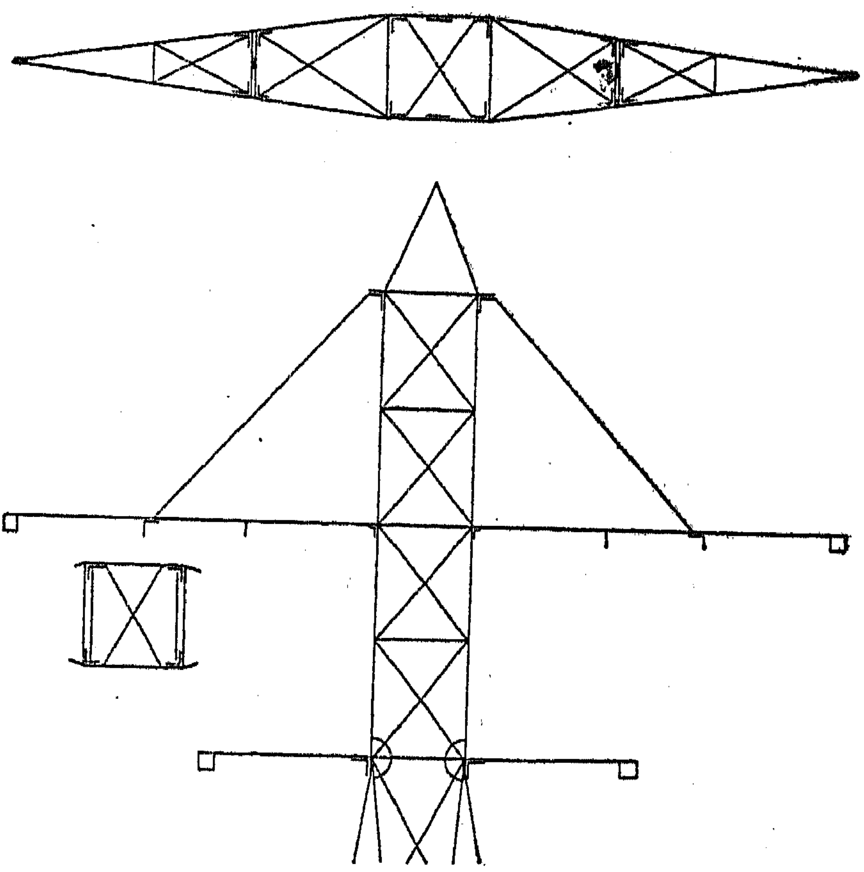


FIG. 14—GREAT WESTERN POWER CO. SKETCH OF TOP OF REINFORCED TRANSPOSITION TOWER.

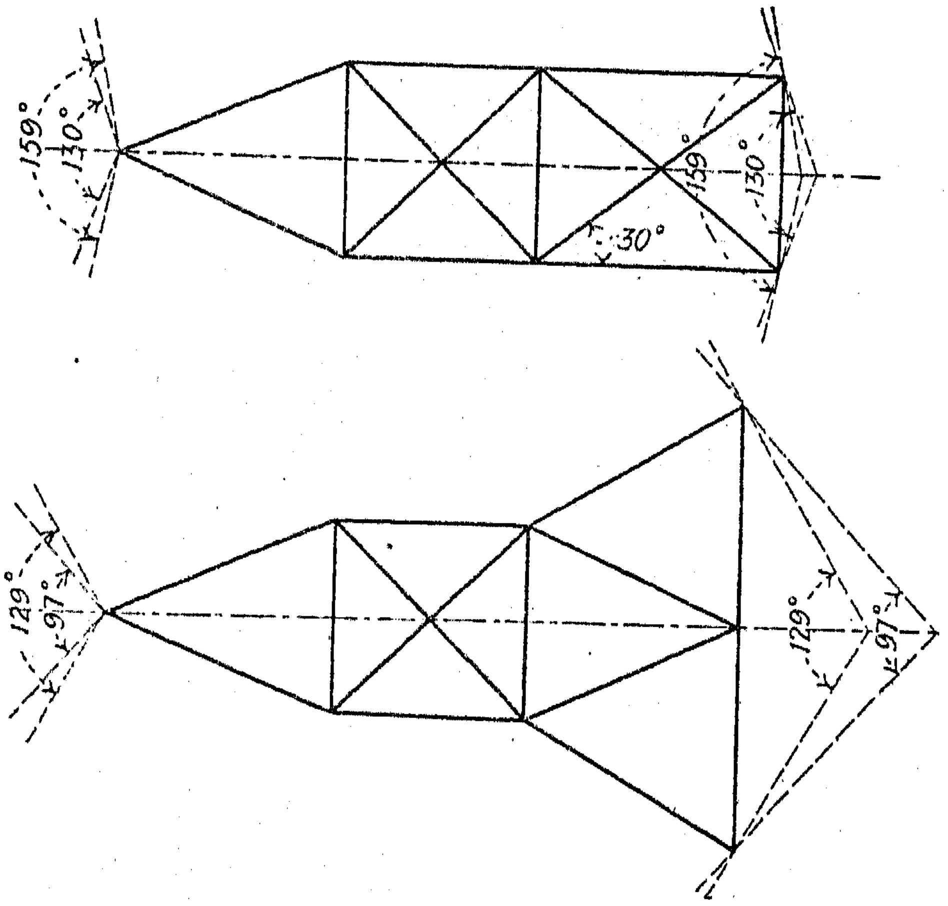


FIG. 15—MISSISSIPPI RIVER POWER CO. SPECIAL CROSSARMS FOR ANGLE TOWER

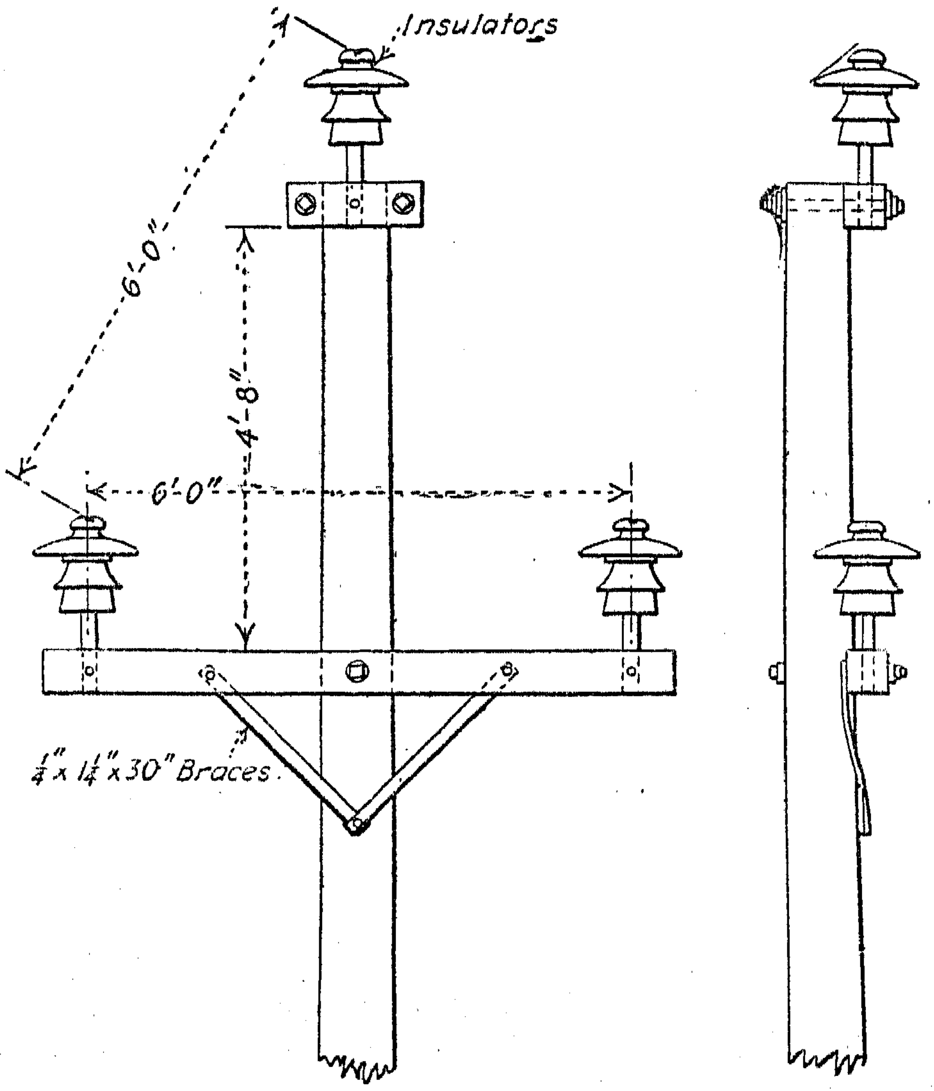


FIG. 16—WESTERN STATES GAS AND ELECTRIC CO. TRIANGULAR CONSTRUCTION OF 60,000-VOLT TRANSMISSION LINE.

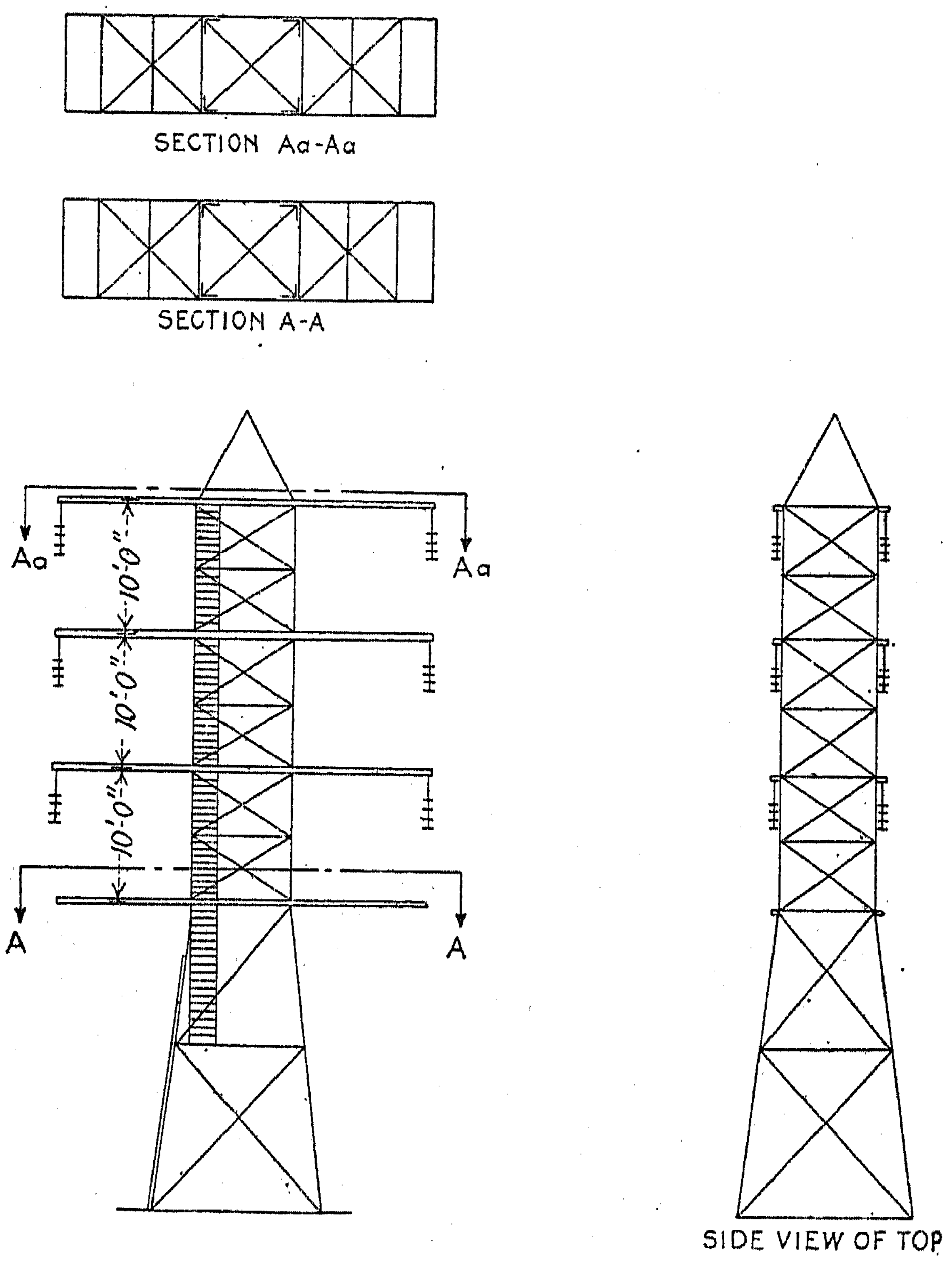


FIG. 17—GREAT WESTERN POWER CO. TOPS OF TWO SPECIAL TOWERS AT ISLETON

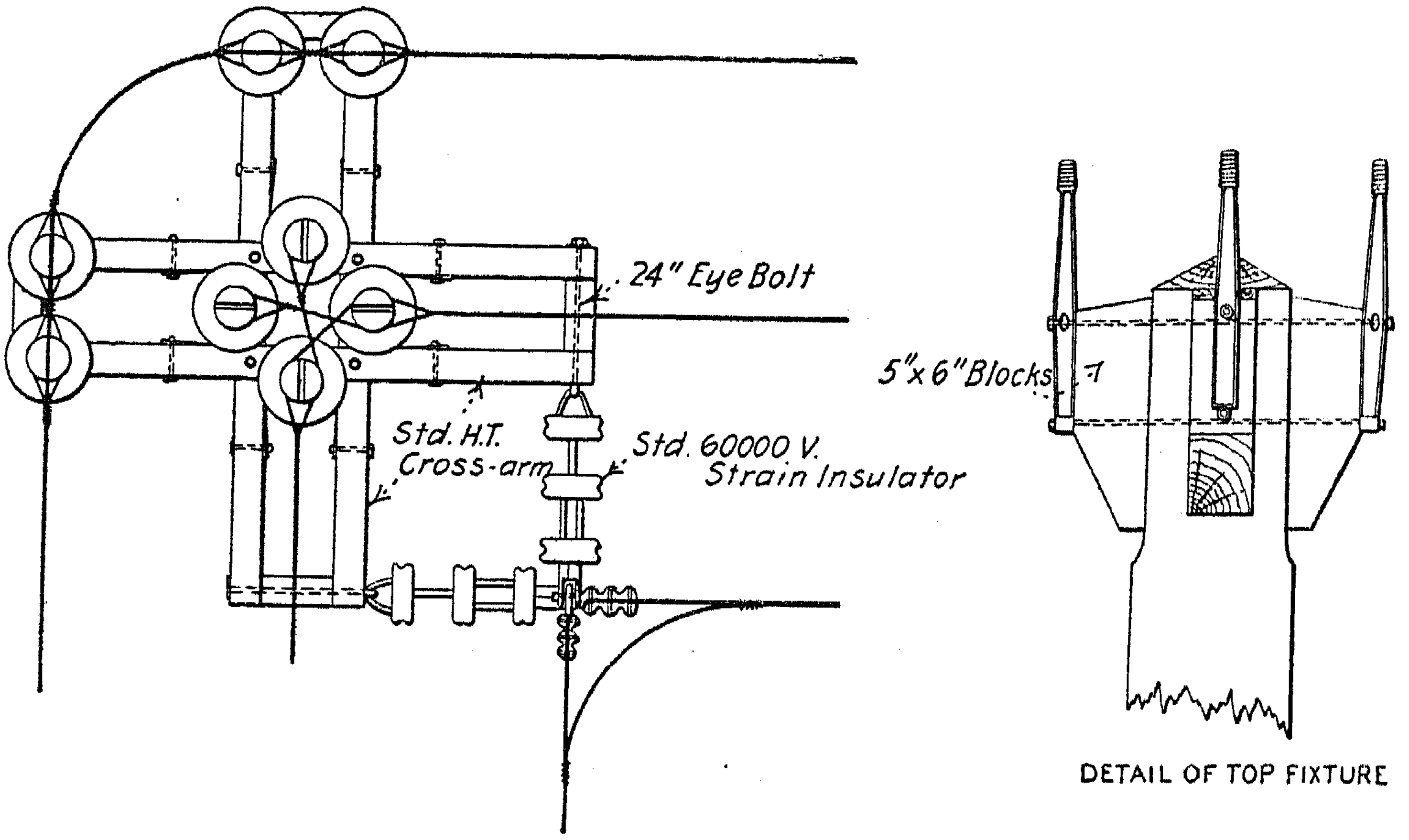


FIG. 18—PUGET SOUND TRACTION LIGHT AND POWER CO. SQUARE TURN ON 60,000-VOLT LINE CONSTRUCTION

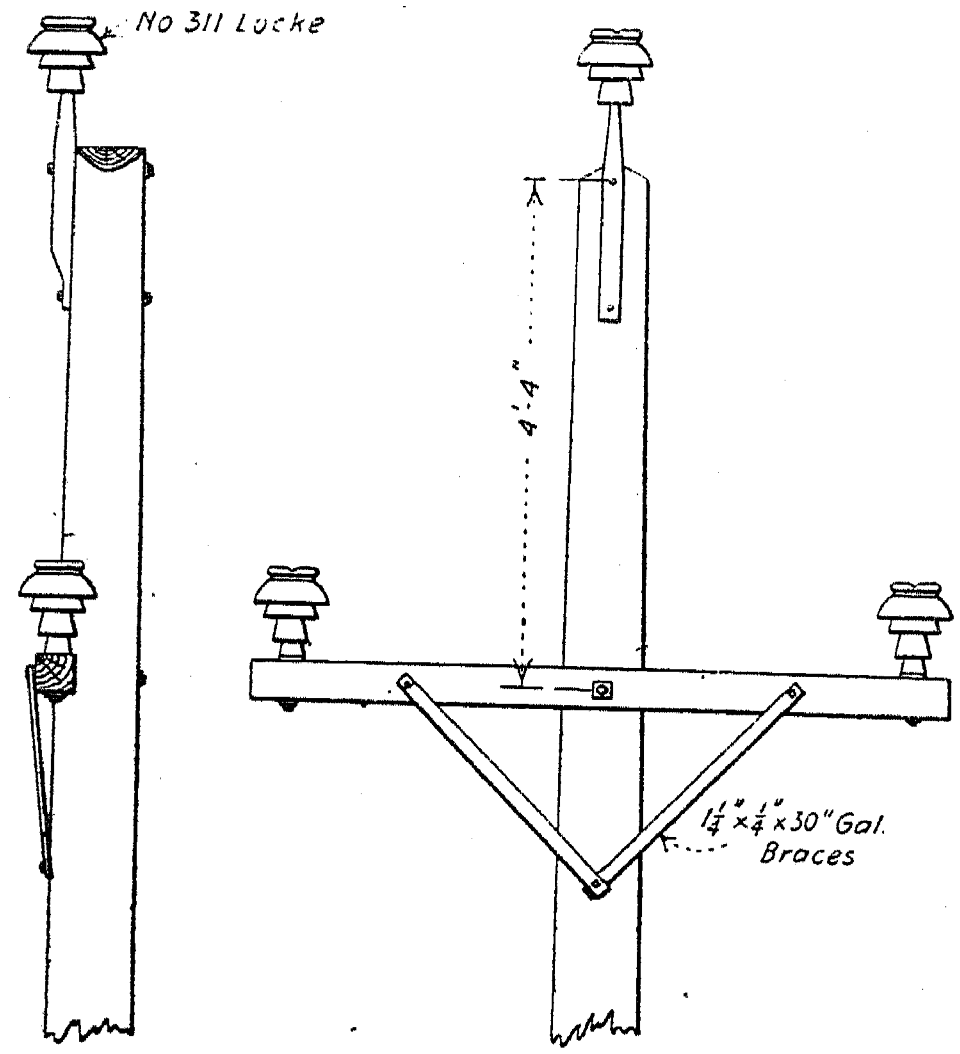


FIG. 19—MT. WHITNEY POWER AND ELECTRIC CO. STANDARD CONSTRUCTION FOR 35,000 VOLTS

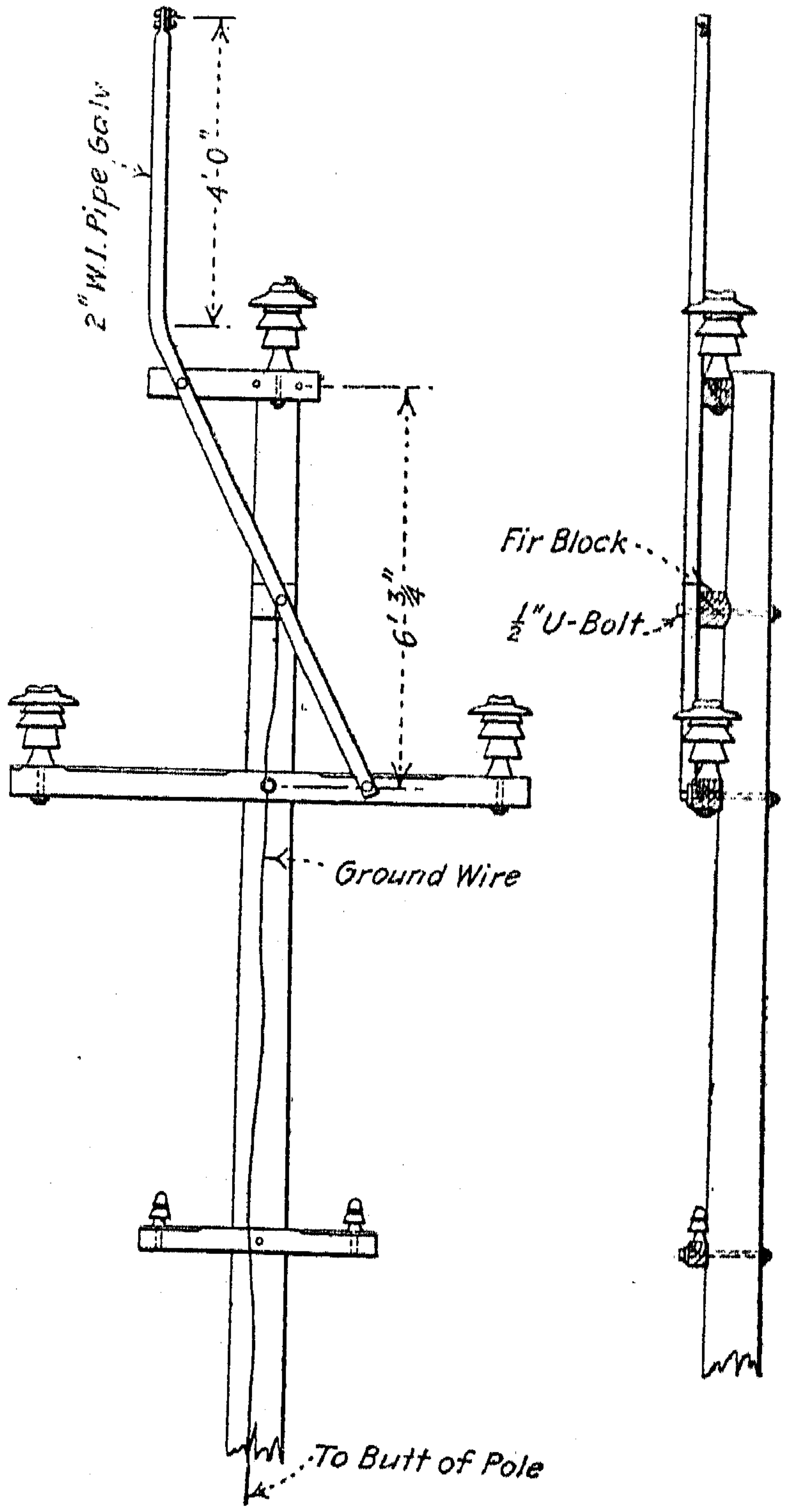


FIG. 20—THE WASHINGTON WATER POWER CO. OVERHEAD GROUND WIRE SUPPORT, ODESSA TRANSMISSION LINE

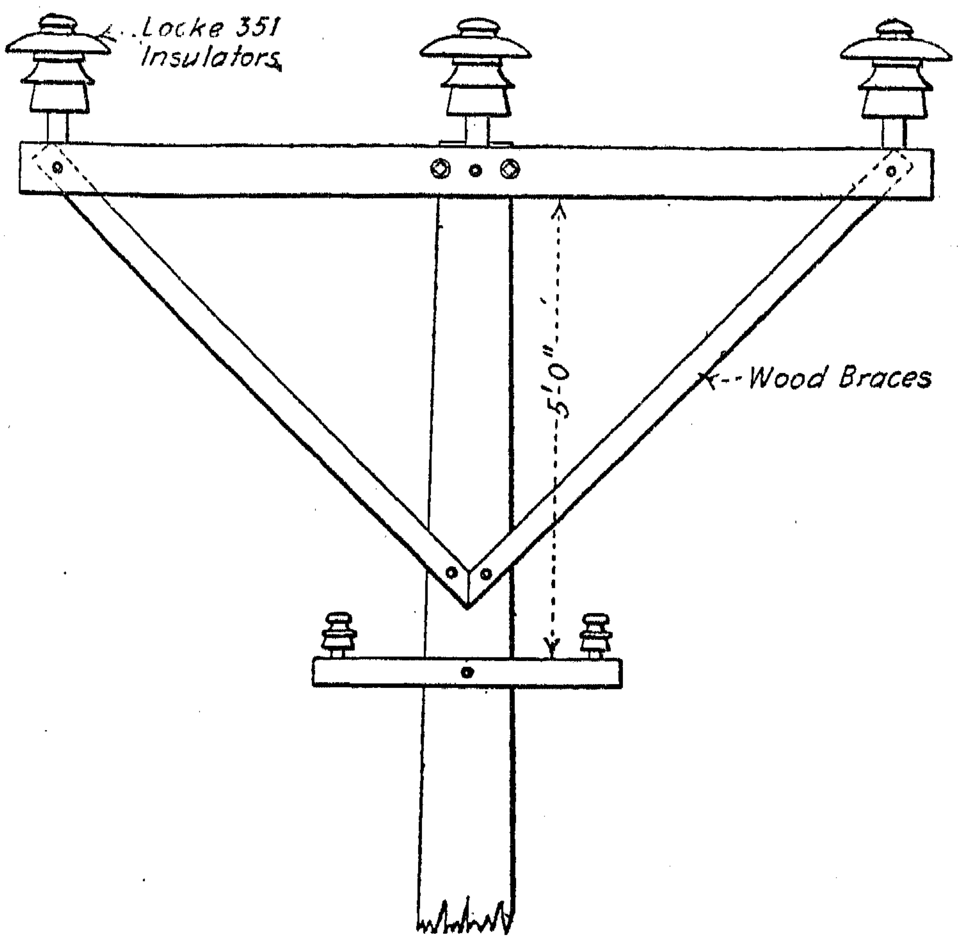


FIG. 21—WESTERN STATES GAS AND ELECTRIC CO. FLAT CONSTRUCTION OF 60,000-VOLT TRANSMISSION LINE.

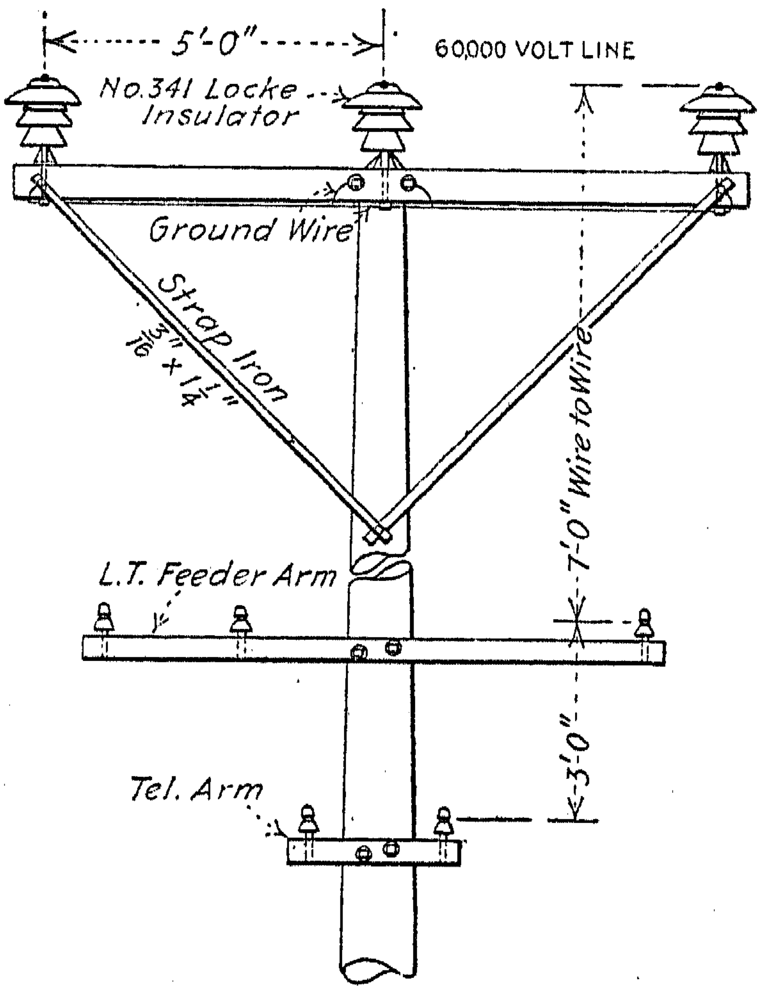


FIG. 22—WASHINGTON WATER POWER CO. POLE TOP CONSTRUCTION FOR WILBUR HARTLINE TRANSMISSION LINE

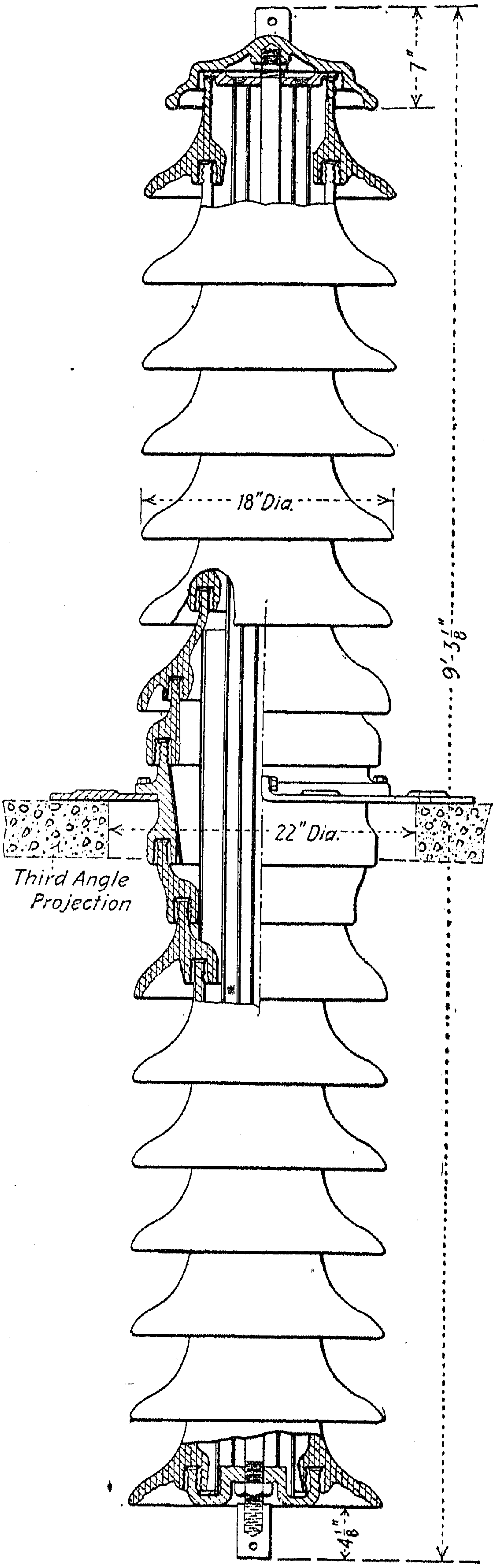


FIG. 23—MEXICAN LIGHT AND POWER CO. 85,000-VOLT ROOF BUSHING

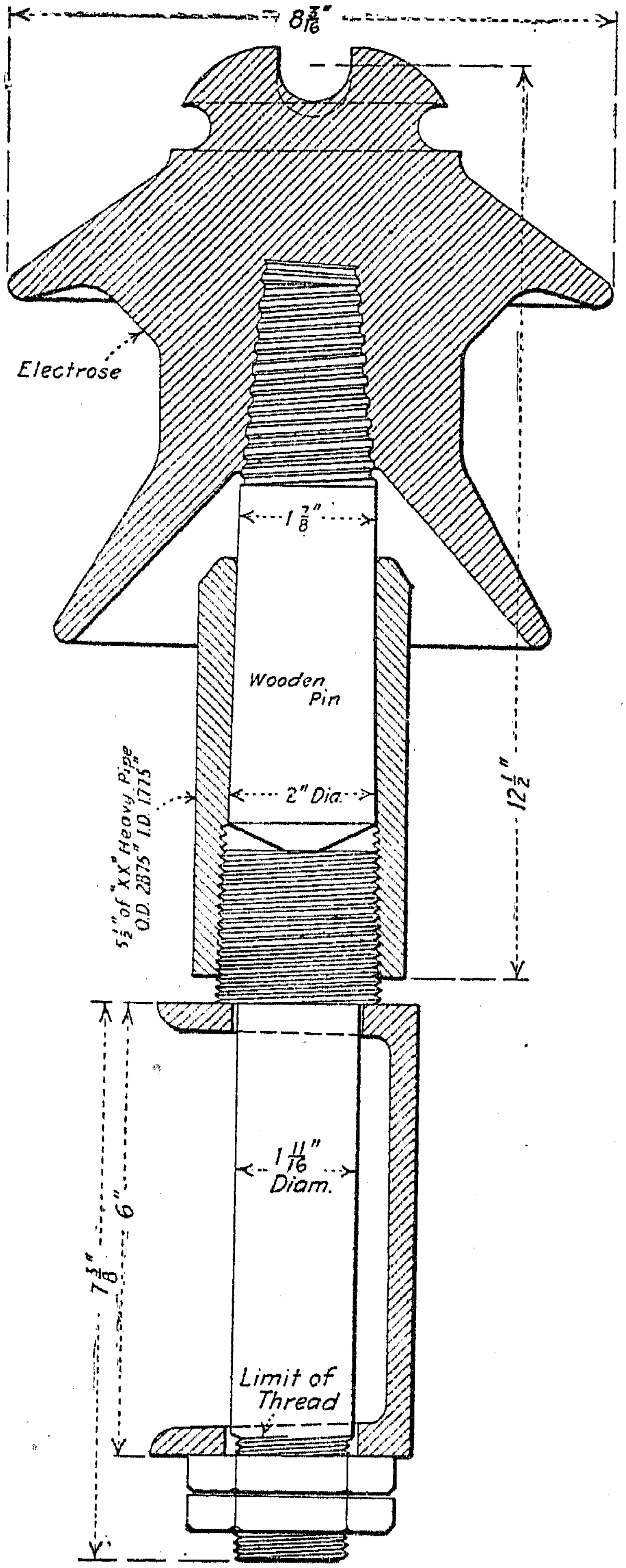


FIG. 24—NIAGARA FALLS POWER CO. INSULATOR AND PIN

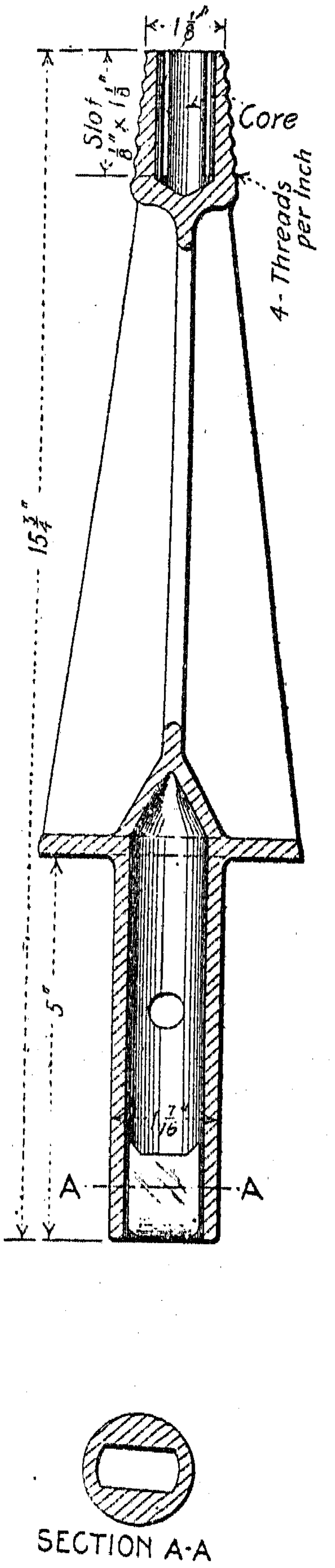


FIG. 25—PUGET SOUND TRACTION, LIGHT & POWER CO. INSULATOR PIN FOR CROSSARM, 60,000-VOLT POLE LINE, HEAVY CONSTRUCTION. SEE FIG. 26

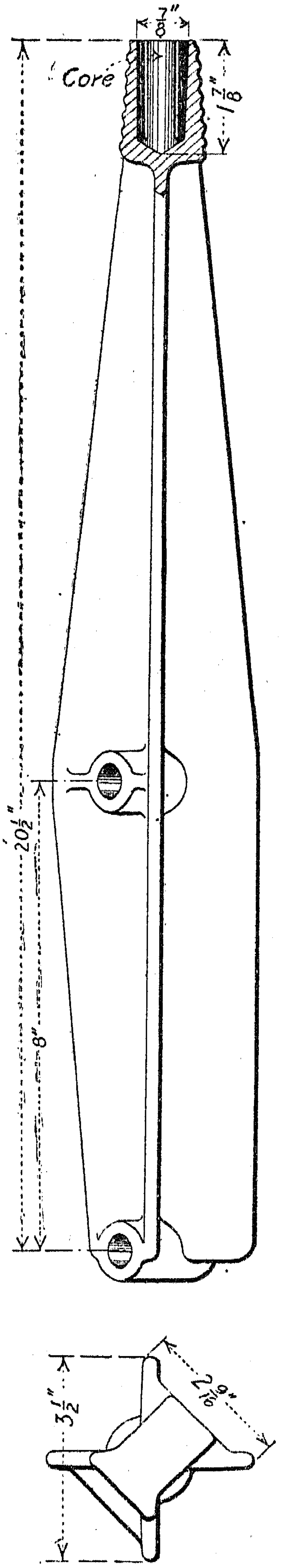


FIG. 26—PUGET SOUND TRACTION, LIGHT AND POWER CO. INSULATOR PIN FOR POLE TOP, 60,000-VOLT POLE LINE, HEAVY CONSTRUCTION. SEE FIG. 25

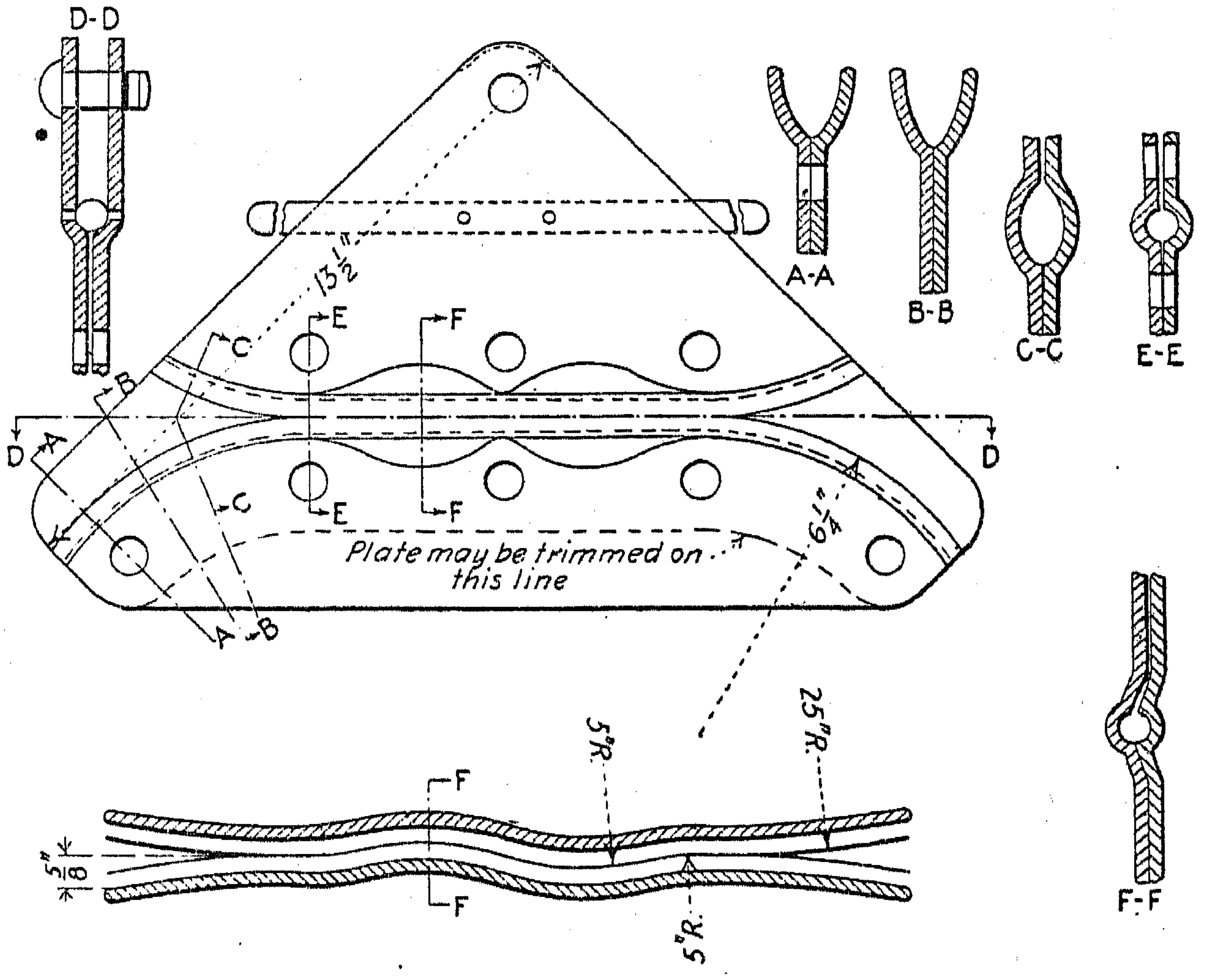


FIG. 27—MISSISSIPPI RIVER POWER CO. CONDUCTOR CABLE CLAMP

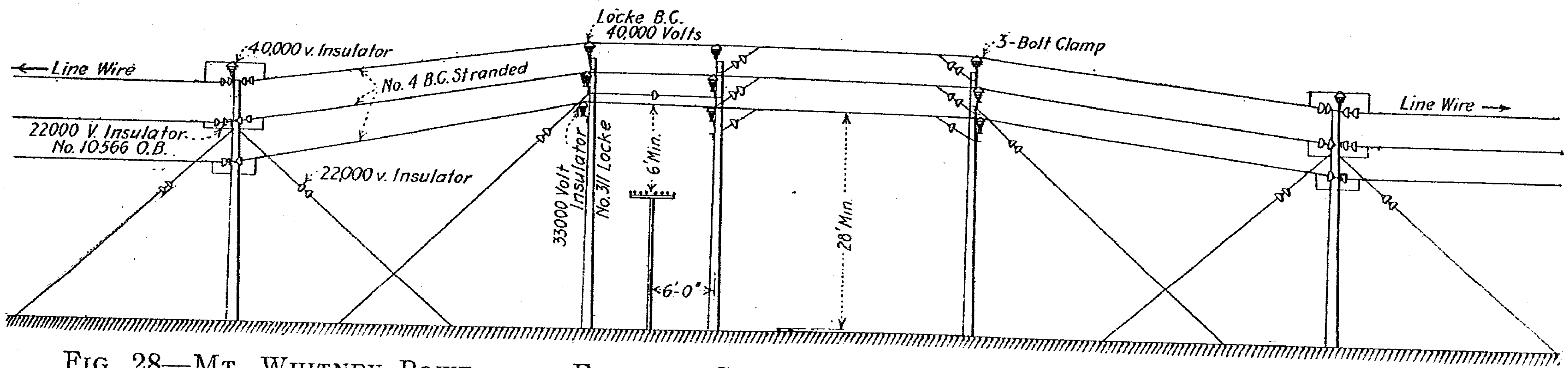


FIG. 28—MT. WHITNEY POWER AND ELECTRIC CO. STANDARD RAILWAY CROSSING NO. 3 FOR 6600- AND 33,000-VOLT LINE.

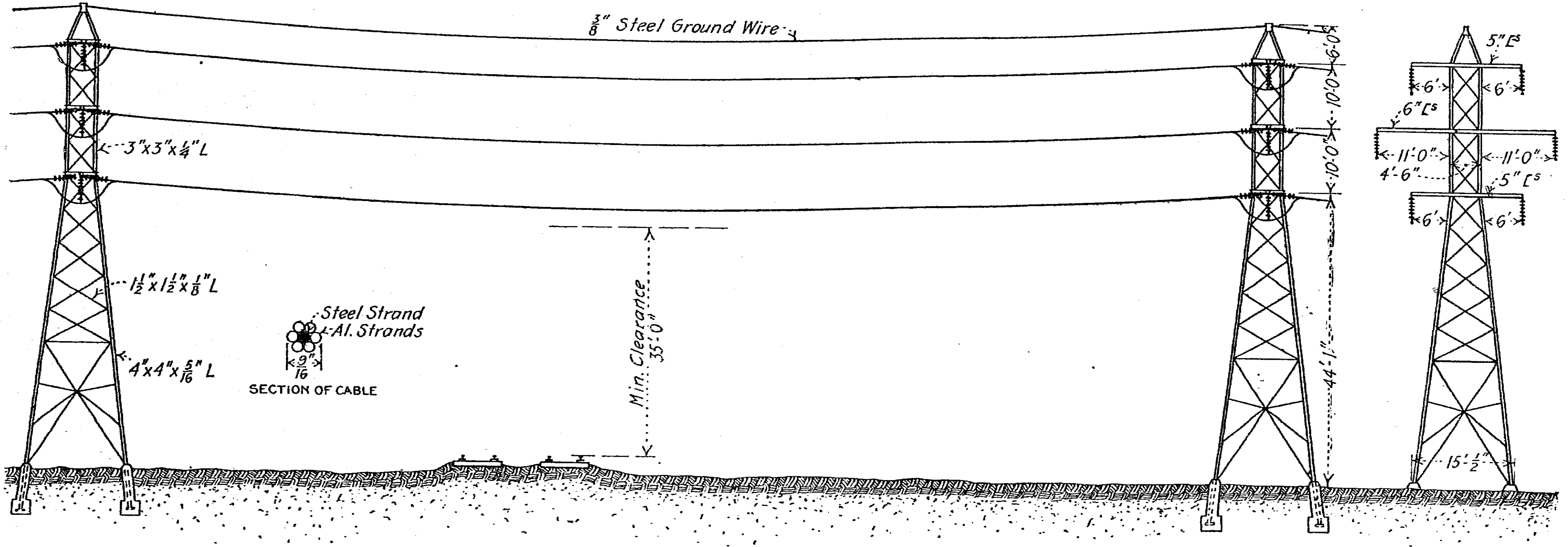


FIG. 29—SOUTHERN SIERRAS POWER CO. PROPOSED CONSTRUCTION AT RAILWAY CROSSINGS.

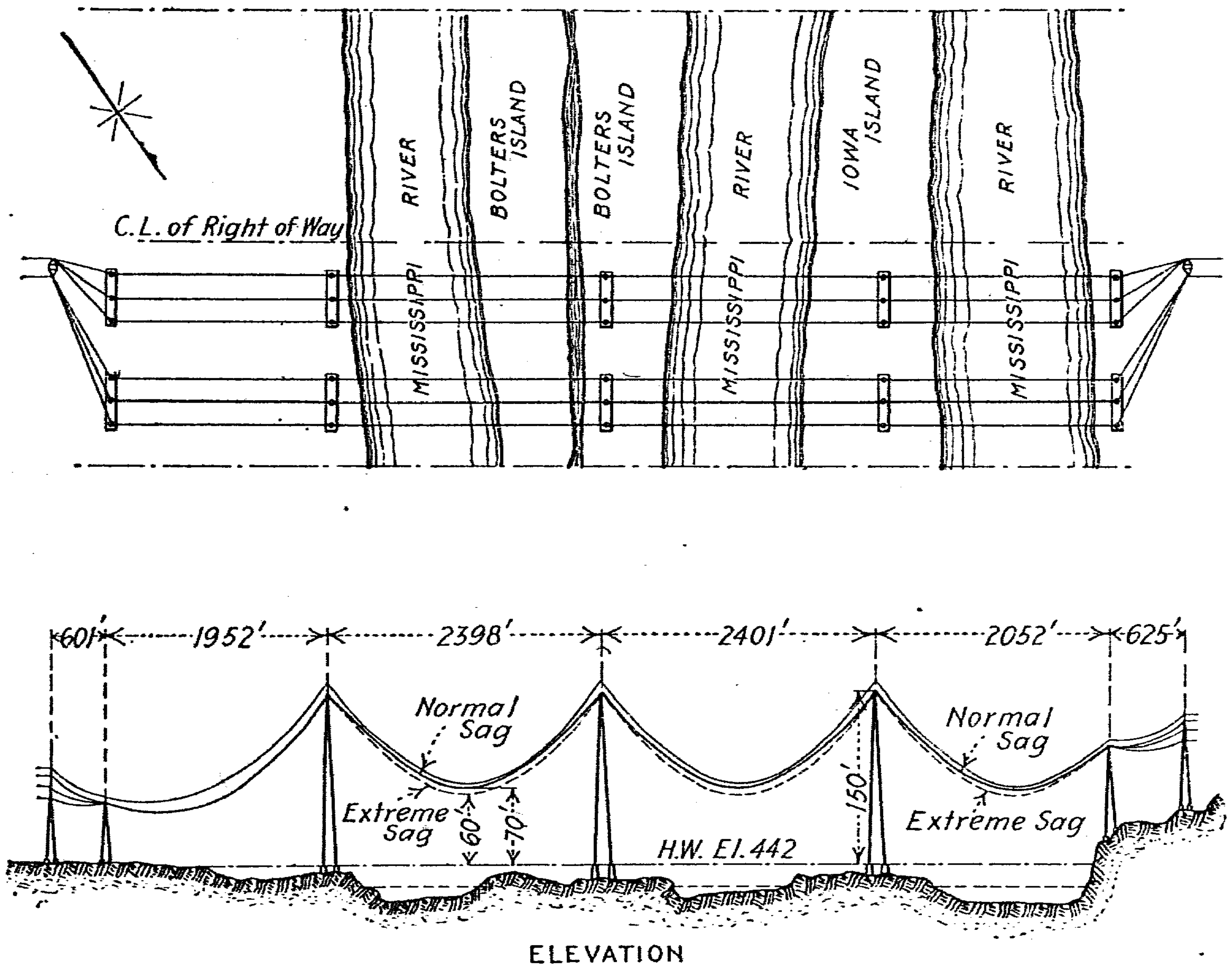


FIG. 30—MISSISSIPPI RIVER POWER CO. TRANSMISSION LINE CROSSING MISSISSIPPI RIVER AT IOWA ISLAND

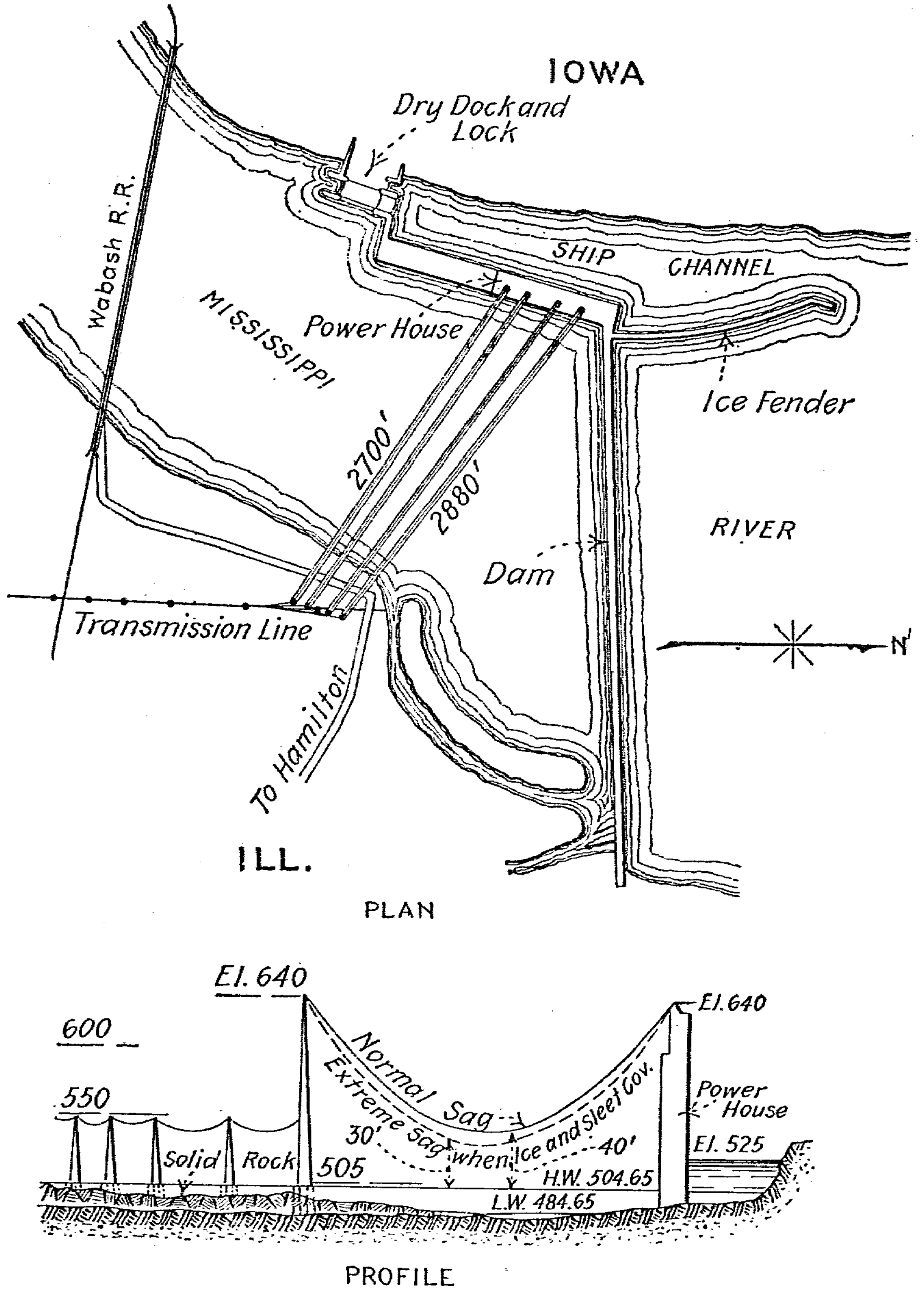


FIG. 31—MISSISSIPPI RIVER POWER CO. TRANSMISSION LINE CROSSING MISSISSIPPI RIVER AT KEOKUK, IOWA

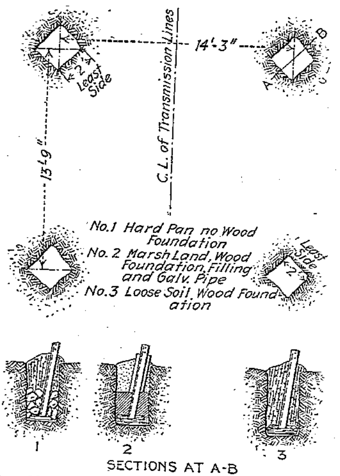

14'-3"
13'-9"
C.L. of Transmission Lines
2'
Least Side
A
B
No.1 Hard Pan no Wood Foundation
No. 2 Marsh Land, Wood Foundation, Filling and Galv. Pipe
No.3 Loose Soil, Wood Foundation
1
2
3
SECTIONS AT A-B

FIG. 32—MEXICAN LIGHT AND POWER CO., LTD. PLAN AND SECTIONS OF TOWER FOUNDATIONS

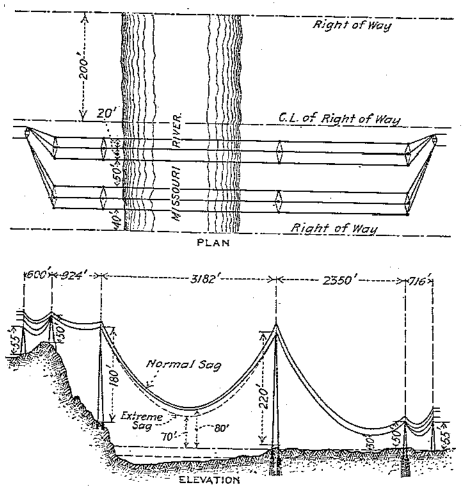


FIG. 33—MISSISSIPPI RIVER POWER CO. TRANSMISSION LINE CROSSING AT MISSOURI RIVER

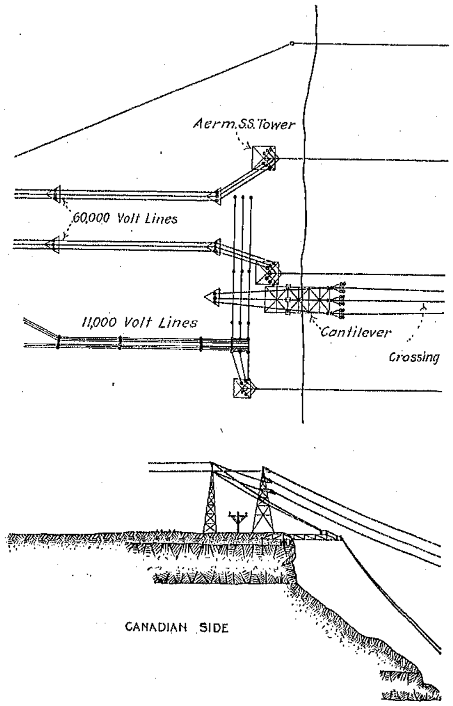


Fig. 34—Niagara, Lockport and Ontario Power Co. Profile of Revised Crossing over Niagara Gorge

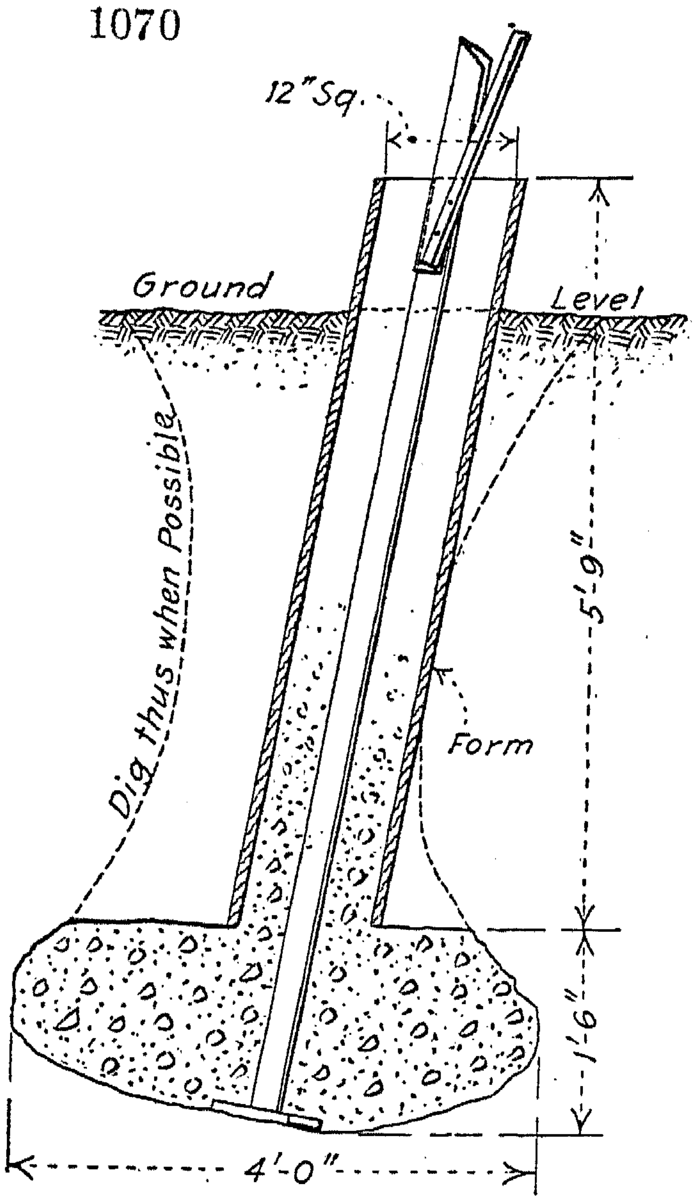


FIG. 35—GREAT WESTERN POWER CO. TOWER FOOTINGS FOR STANDARD TOWERS

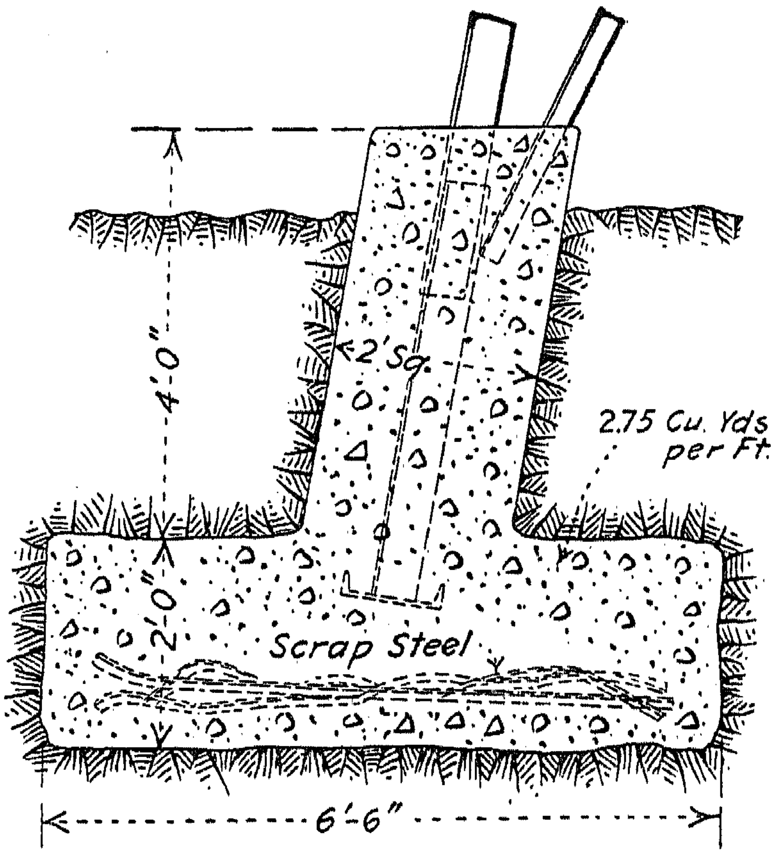


FIG. 36—GREAT WESTERN POWER CO. STUB FOOTINGS FOR 37 DEG. ANGLE TOWER ON COMPRESSION SIDE OF ANGLES

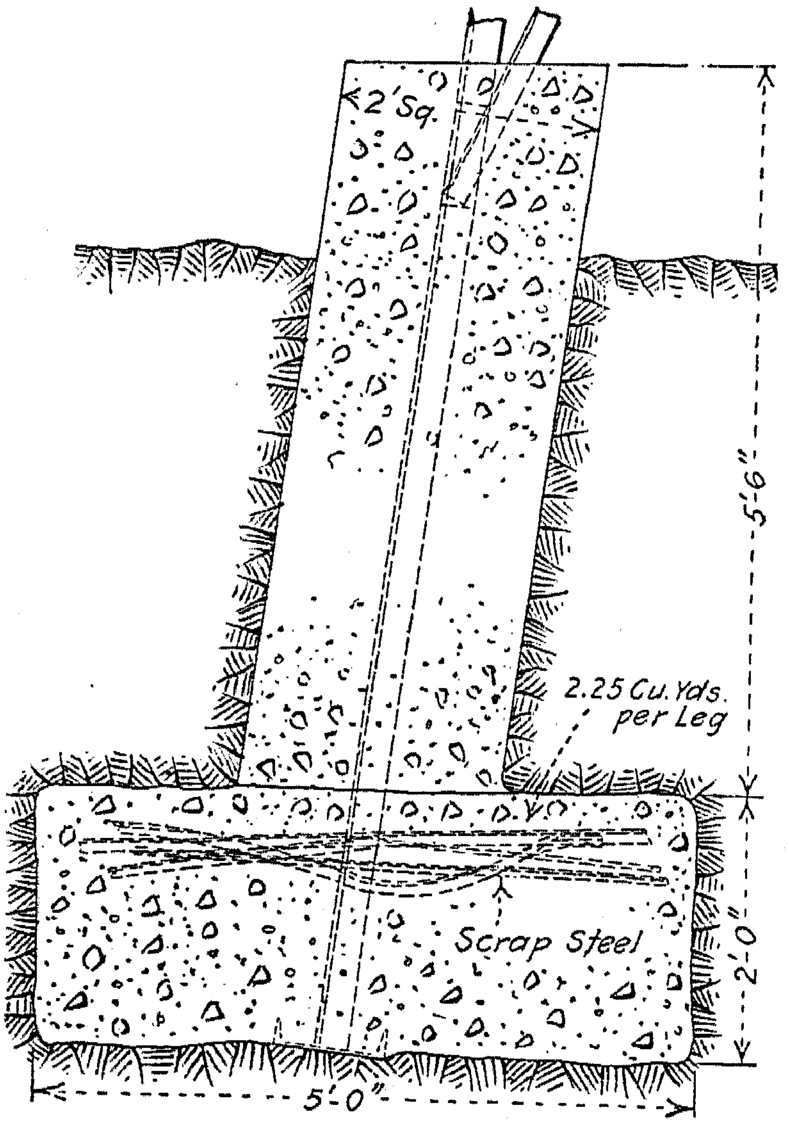


FIG. 37—GREAT WESTERN POWER CO. FOOTINGS FOR ANCHOR TOWER ON TENSION SIDE OF ANGLES

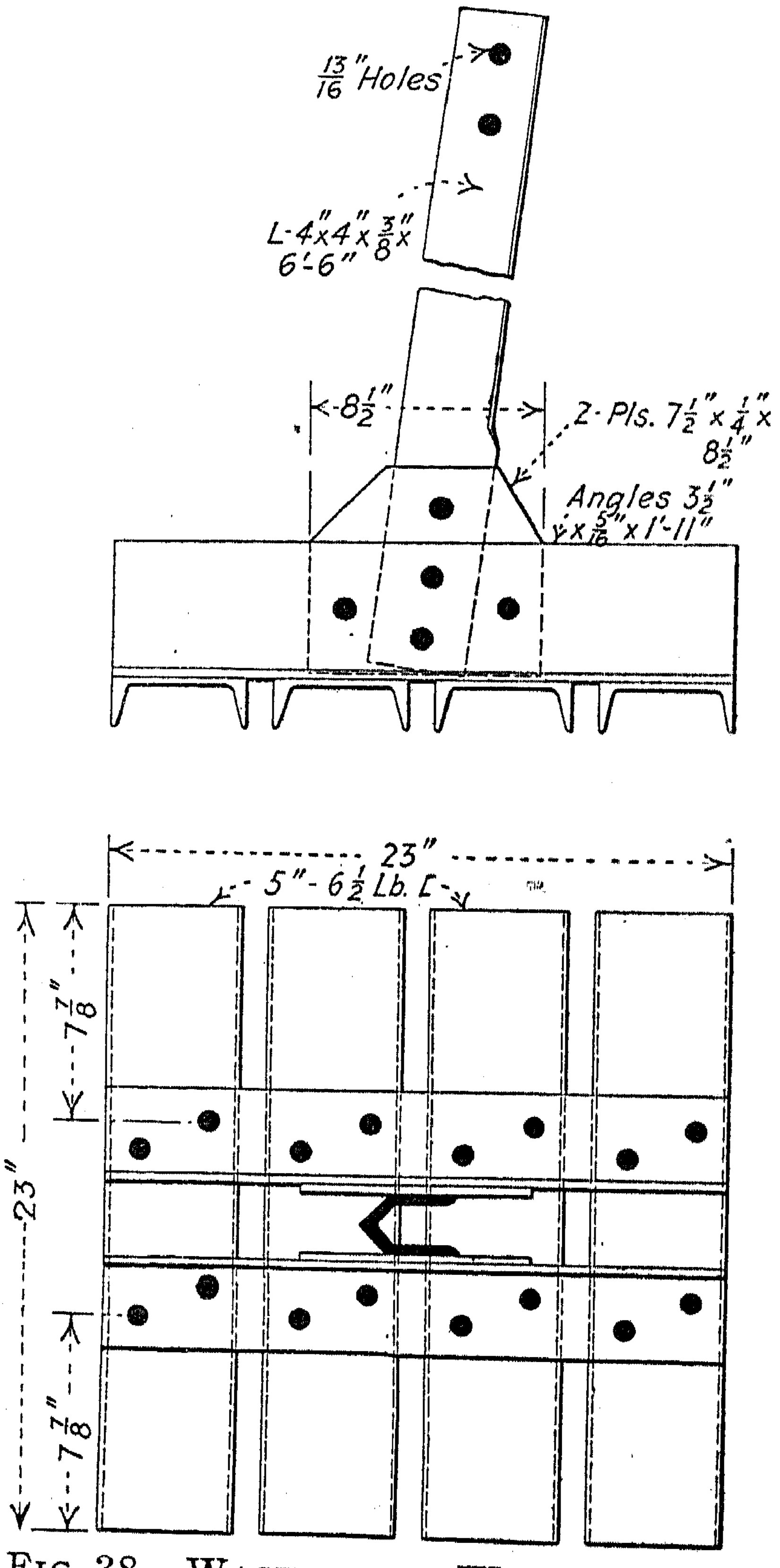


FIG. 38—WASHINGTON WATER POWER CO. GRAVEL ANCHOR FOR STEEL TOWERS

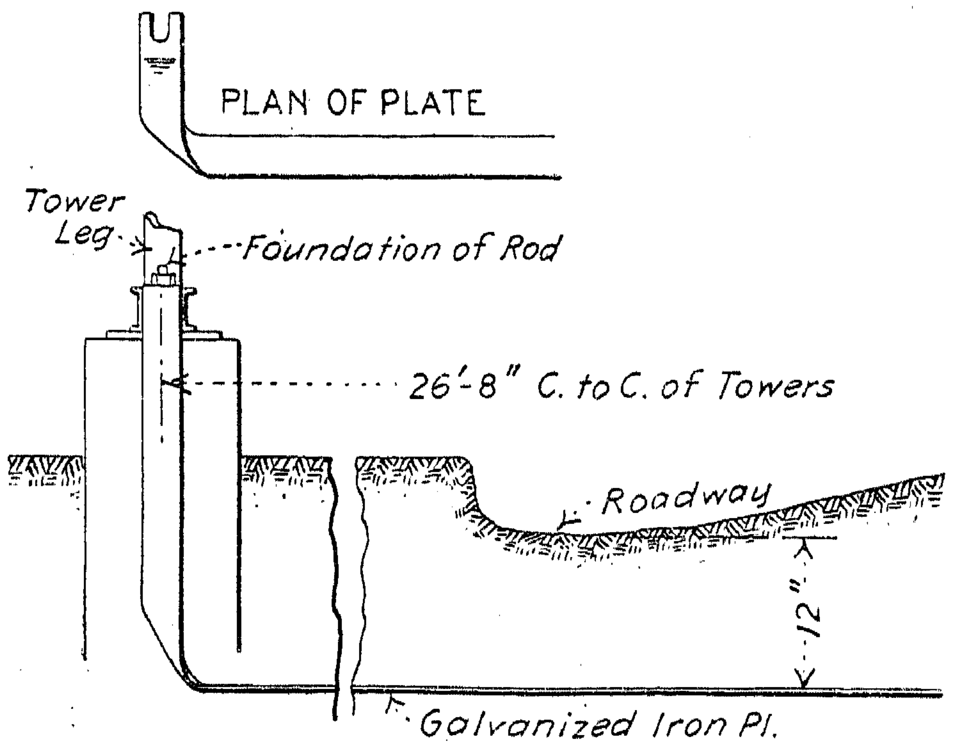


FIG. 39—NIAGARA, LOCKPORT AND ONTARIO POWER CO. GROUND FOR TRANSMISSION LINE TOWERS

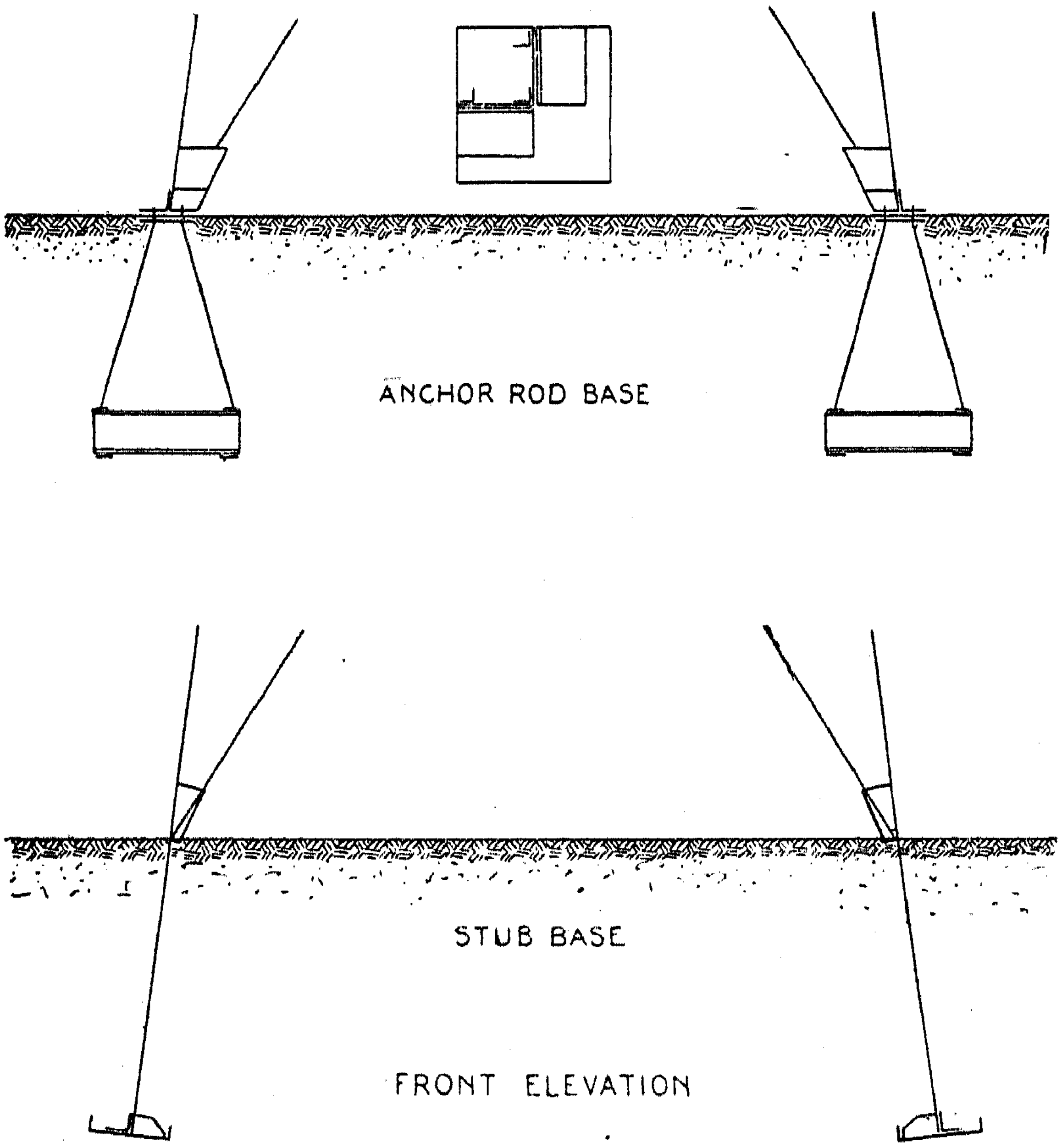


FIG. 40—GREAT WESTERN POWER CO. BASES FOR 37-DEG. ANGLE TOWER

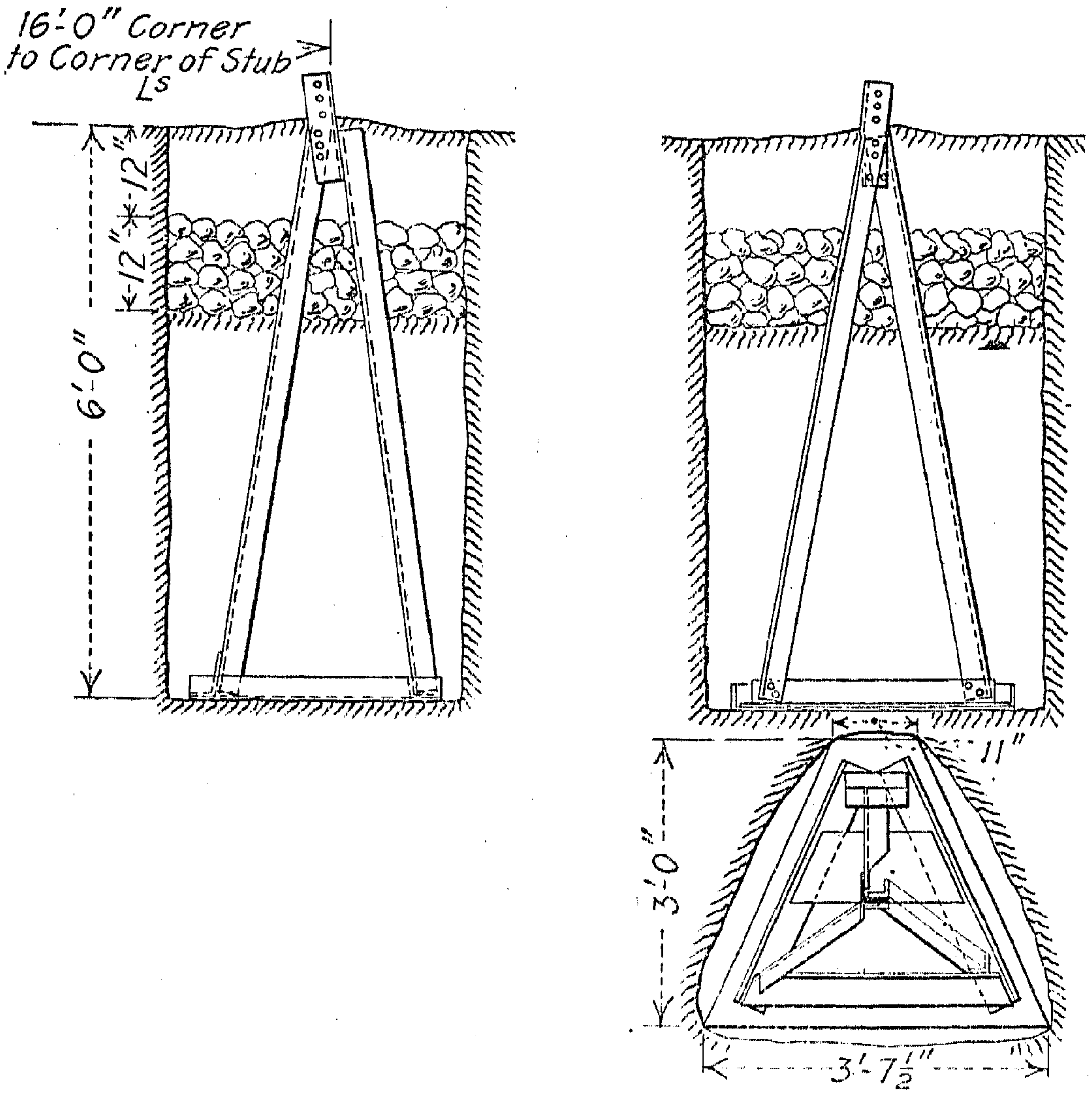
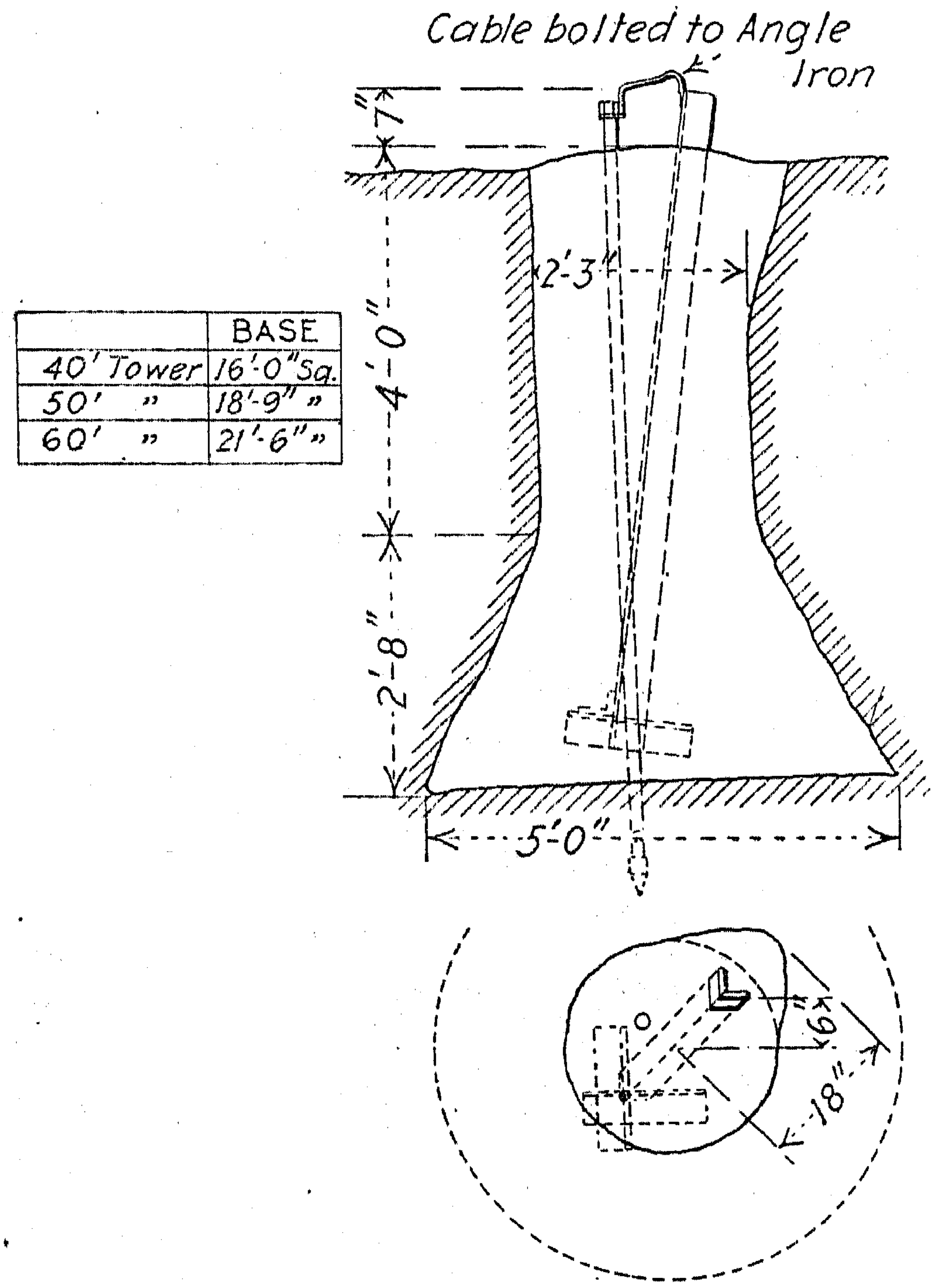


FIG. 41—PENNSYLVANIA WATER AND POWER CO. FOUNDATION FOR 40-FT. LIGHT SECTION TOWERS



	BASE
40' Tower	16'-0" Sq.
50' "	18'-9" "
60' "	21'-6" "

FIG. 42—PENNSYLVANIA WATER AND POWER CO. CONCRETE FOUNDATION FOR HEAVY TOWERS

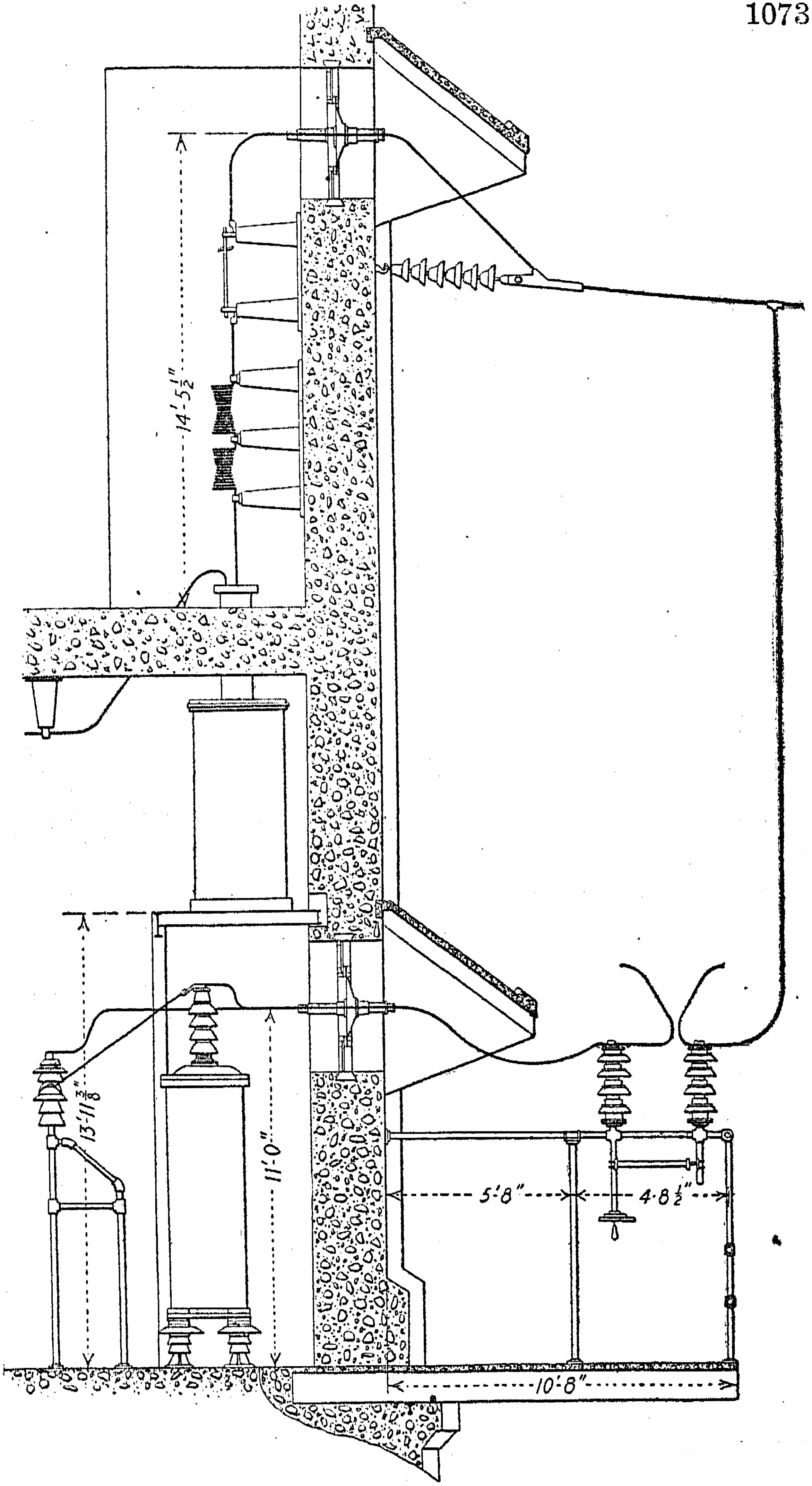


FIG. 43—PENNSYLVANIA WATER AND POWER CO. CROSS-SECTION THROUGH TRANSFORMER HOUSE, SHOWING OUTGOING LINE

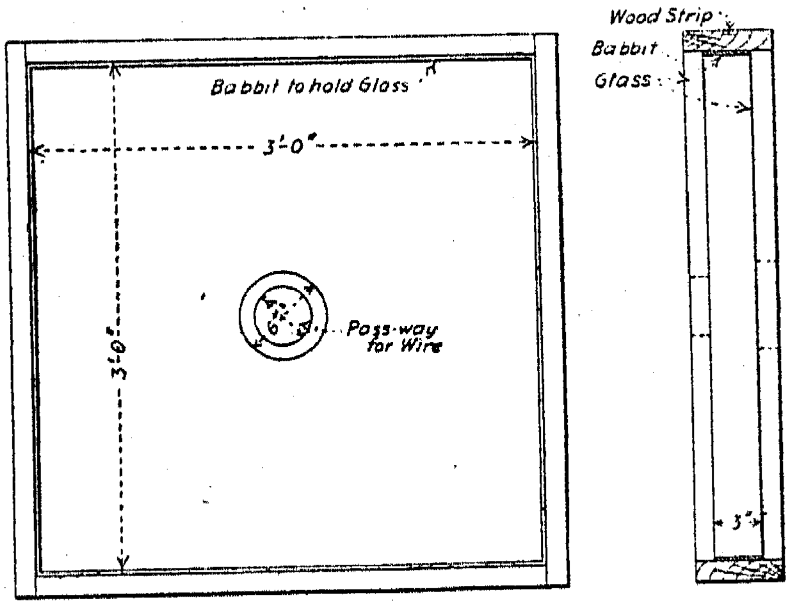


FIG. 44—WESTERN STATES GAS AND ELECTRIC CO. STANDARD EXIT FOR TRANSMISSION WIRES AT SUBSTATIONS

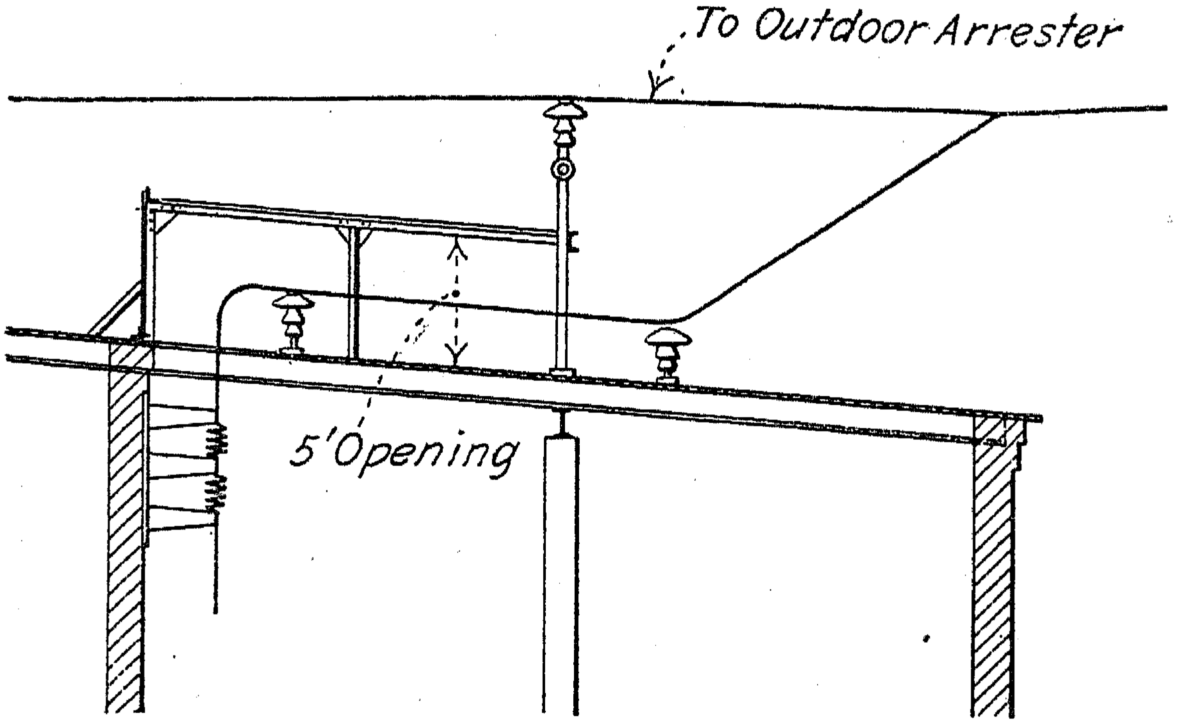


FIG. 45—MEXICAN LIGHT AND POWER CO. PROPOSED ROOF ENTRANCE FOR HIGH-TENSION LINES AT NONOALCO SUBSTATION

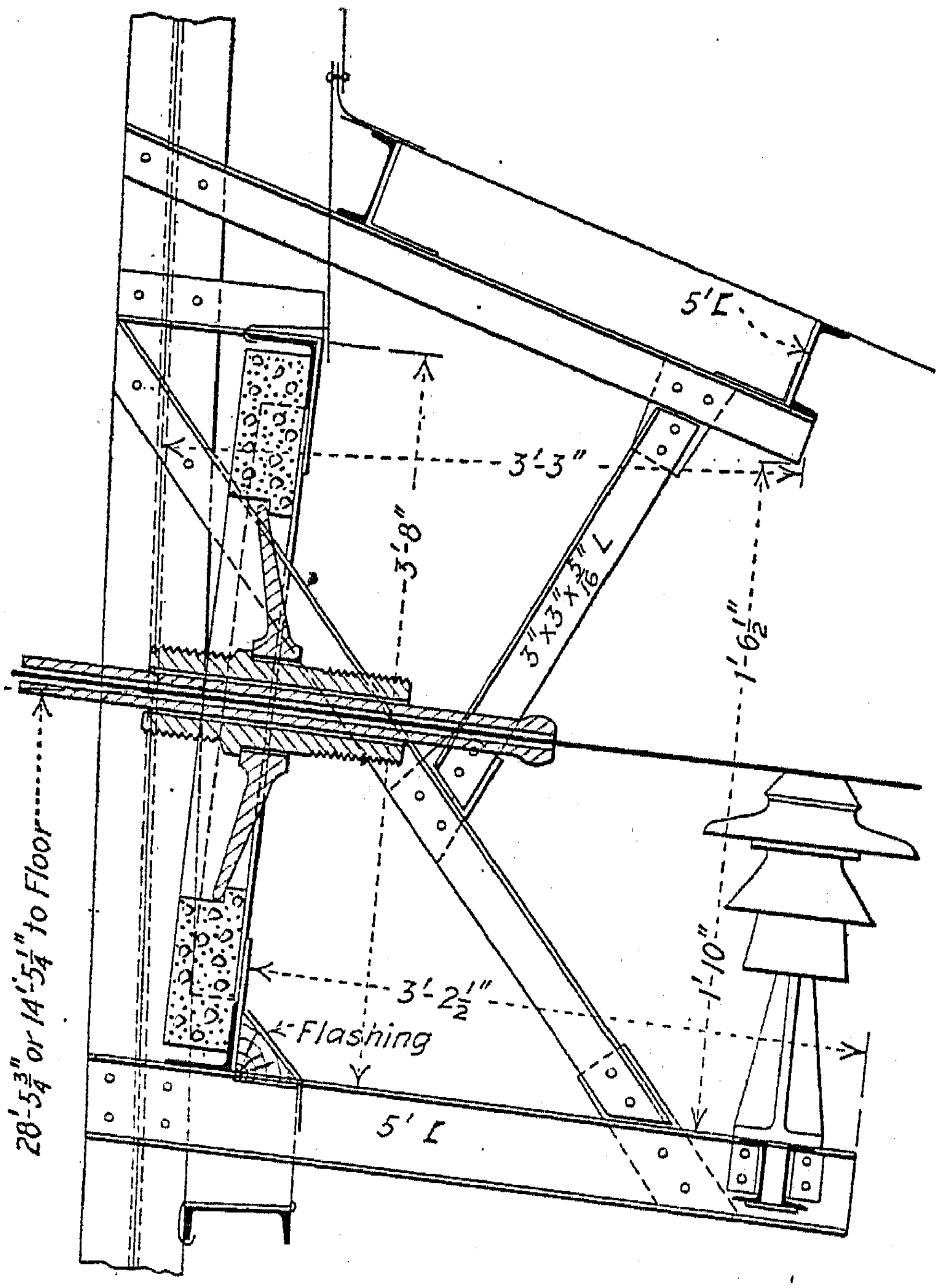


FIG. 46—WASHINGTON WATER POWER CO 60,000-VOLT LINE ENTRANCE

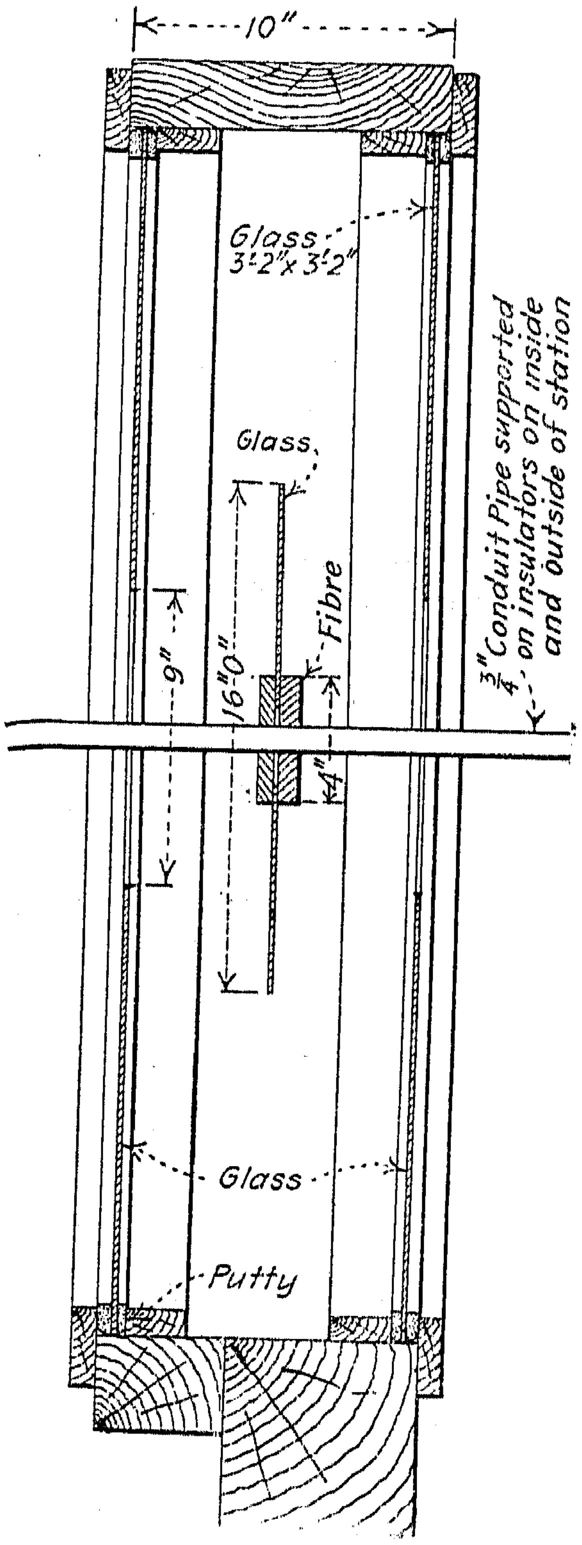

10"
Glass 3'-2"x3'-2"
Glass
9"
16"0"
Fibre
4"
¾" Conduit Pipe supported on insulators on inside and outside of station
Glass
Putty

FIG. 47—WASHINGTON WATER POWER CO. DETAIL OF WALL ENTRANCE FOR HIGH-TENSION LINE, ODESSA SUBSTATION

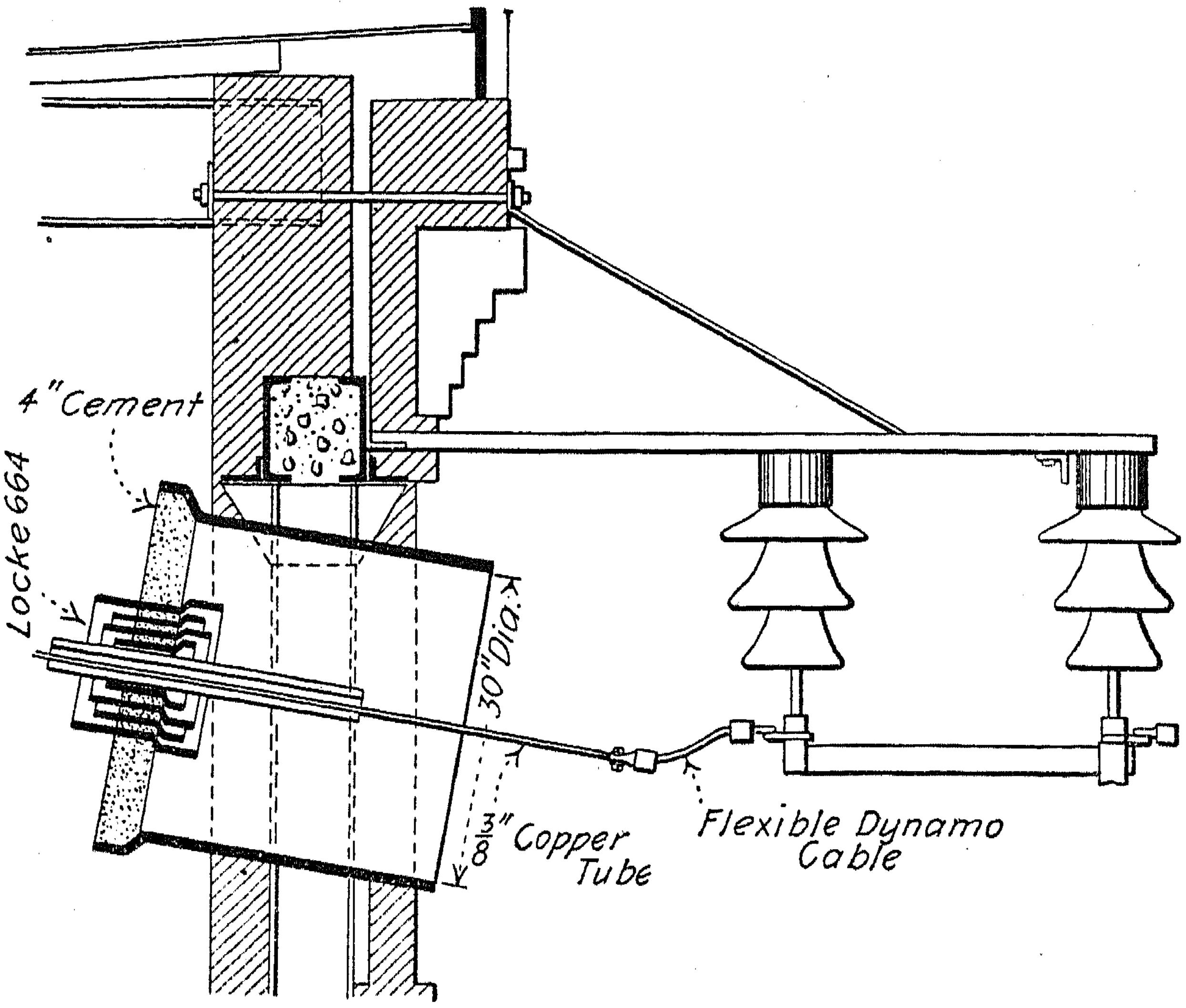


FIG. 48—NIAGARA, LOCKPORT AND ONTARIO POWER CO. DETAIL OF HIGH-TENSION OUTLET THROUGH WALL

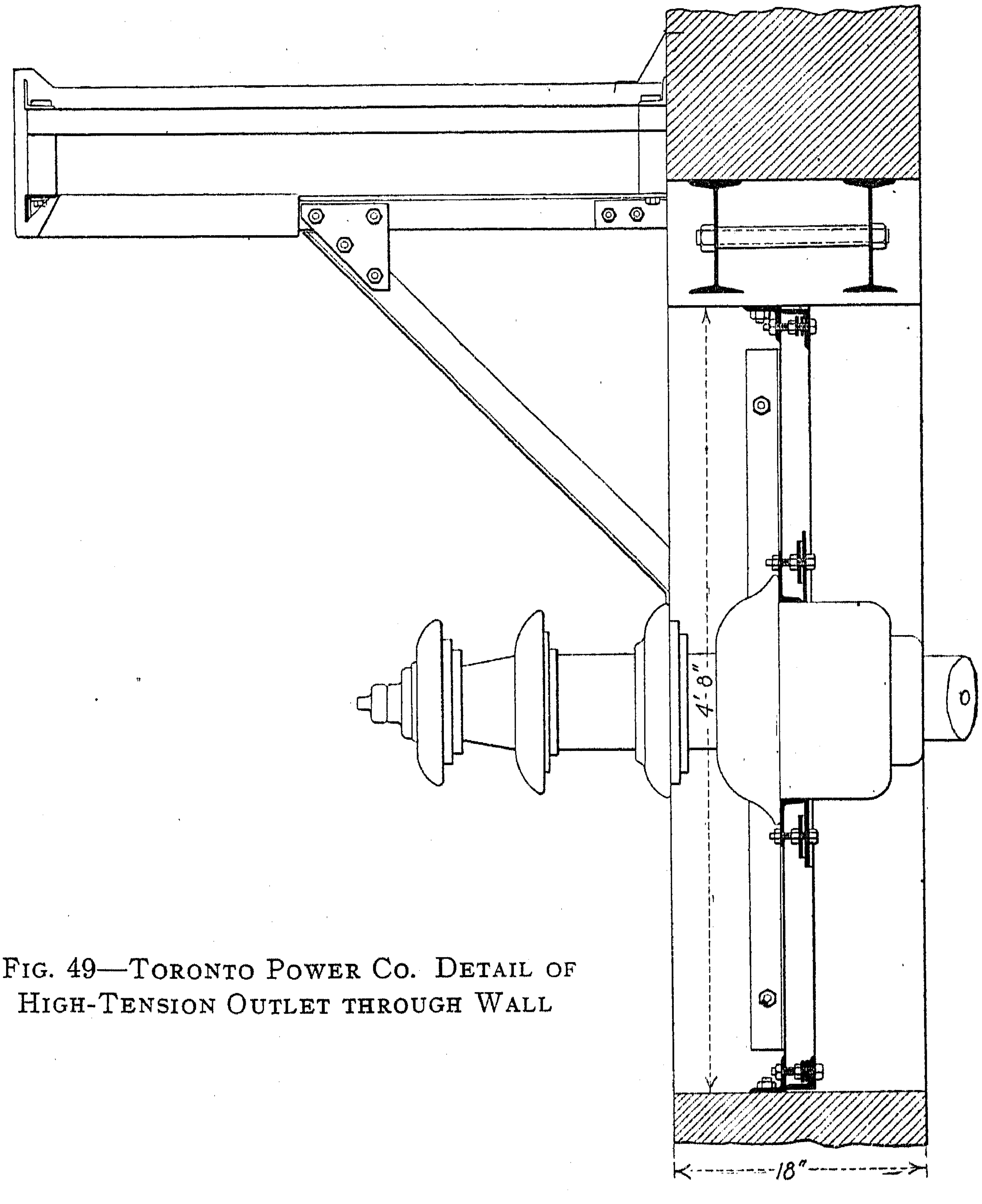


FIG. 49—TORONTO POWER CO. DETAIL OF HIGH-TENSION OUTLET THROUGH WALL

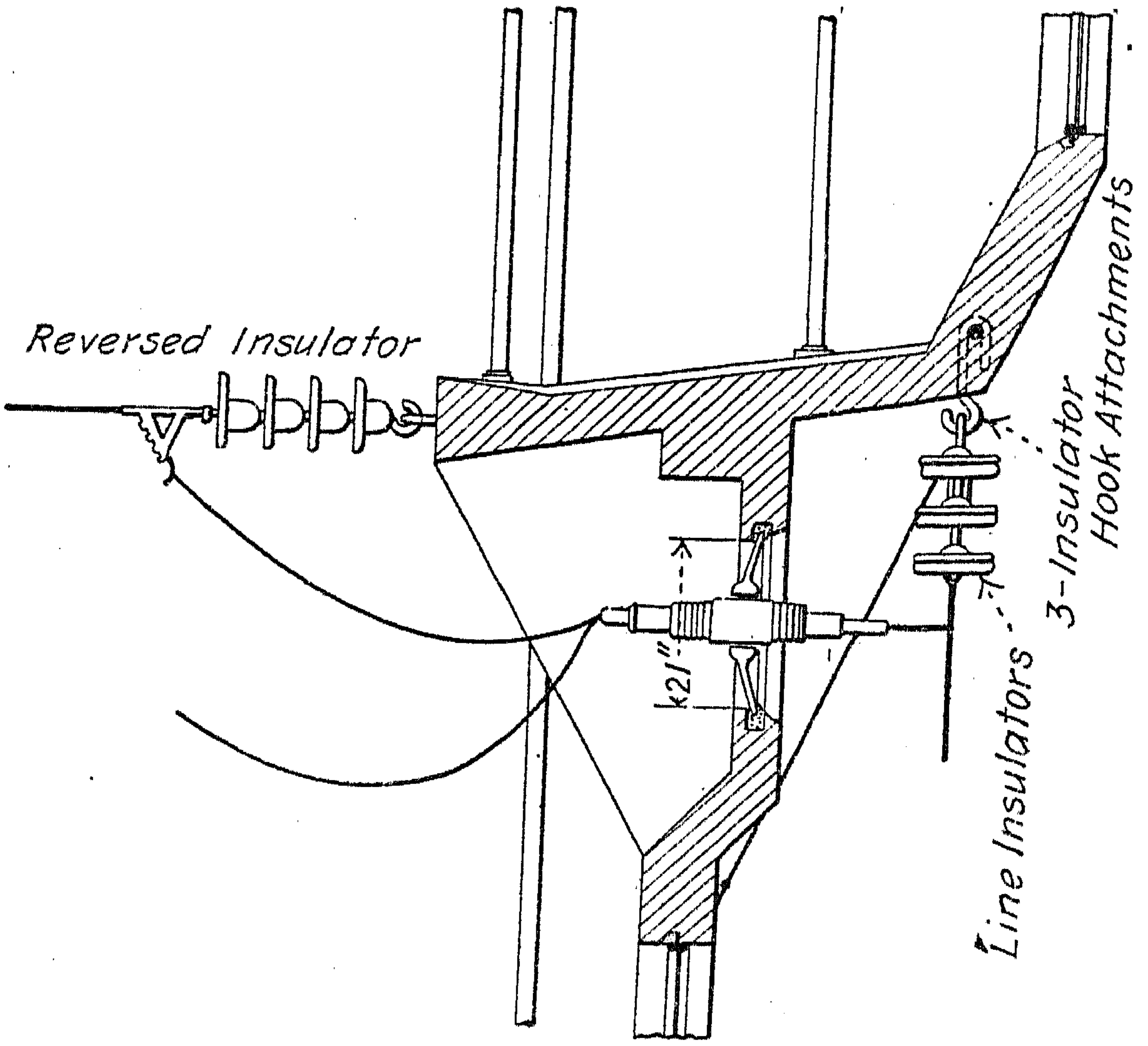


FIG. 50—PORTLAND RAILWAY, LIGHT AND POWER CO. ARRANGEMENT OF OUTGOING LINE BUSHING

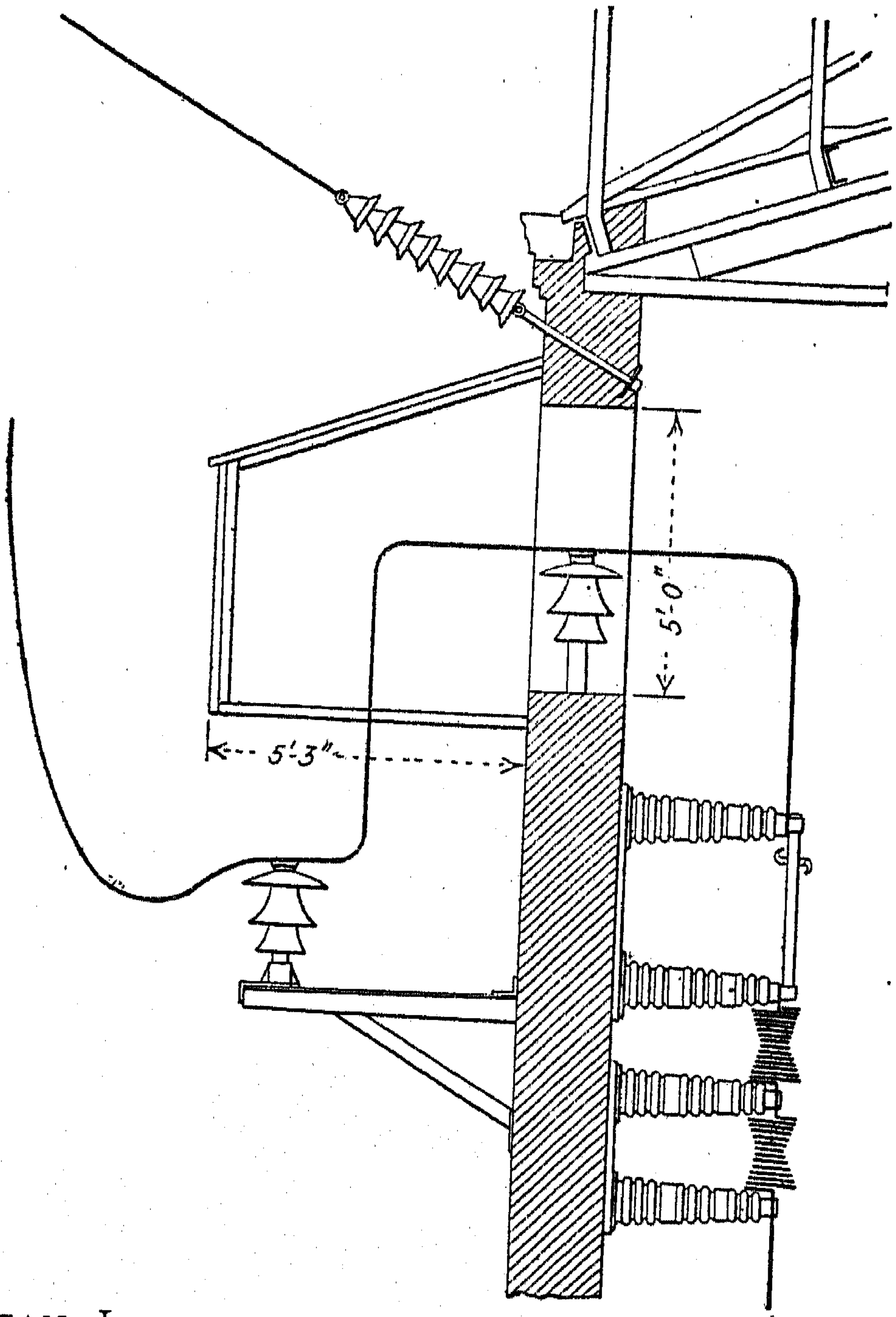


FIG. 51—MEXICAN LIGHT AND POWER CO., LTD. ARRANGEMENT OF OUTLET FOR LINE FOR 85,000 VOLTS AT NECAXA POWER HOUSE NO. 1

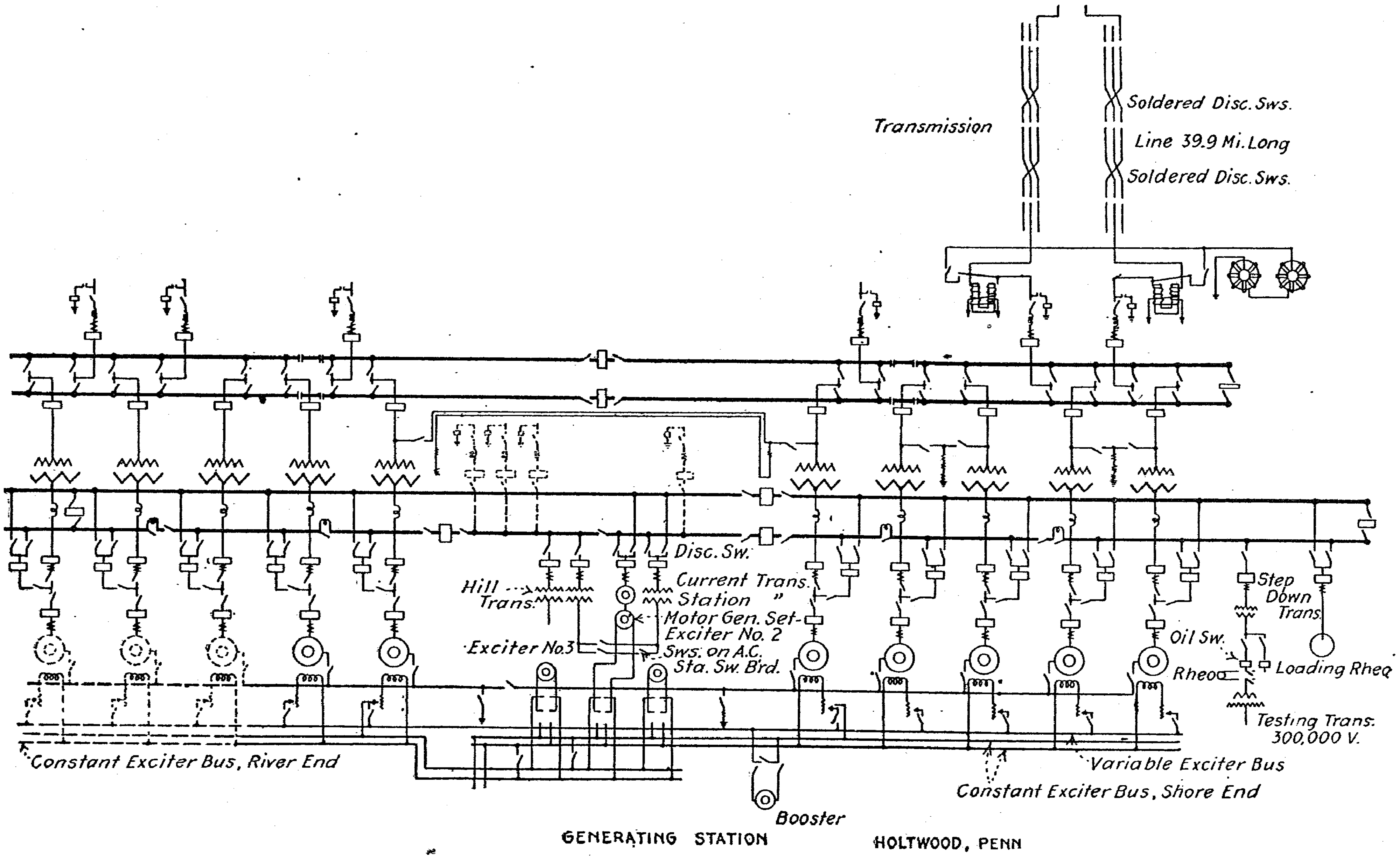


FIG. 52—PENNSYLVANIA WATER AND POWER CO. DIAGRAM OF GENERATING AND TRANSMISSION SYSTEM

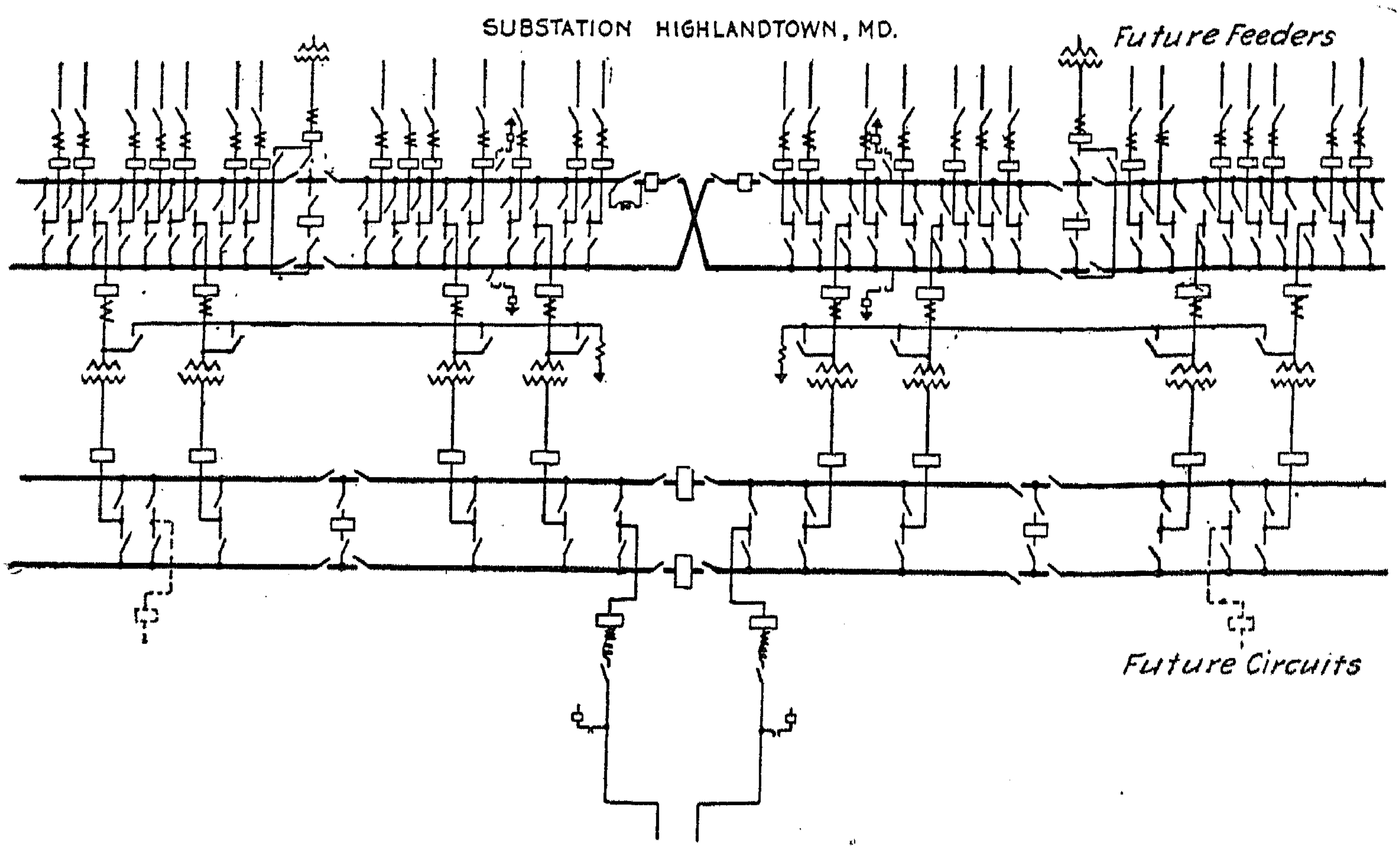


FIG. 53—PENNSYLVANIA WATER AND POWER CO. DIAGRAM OF SUBSTATION CIRCUITS

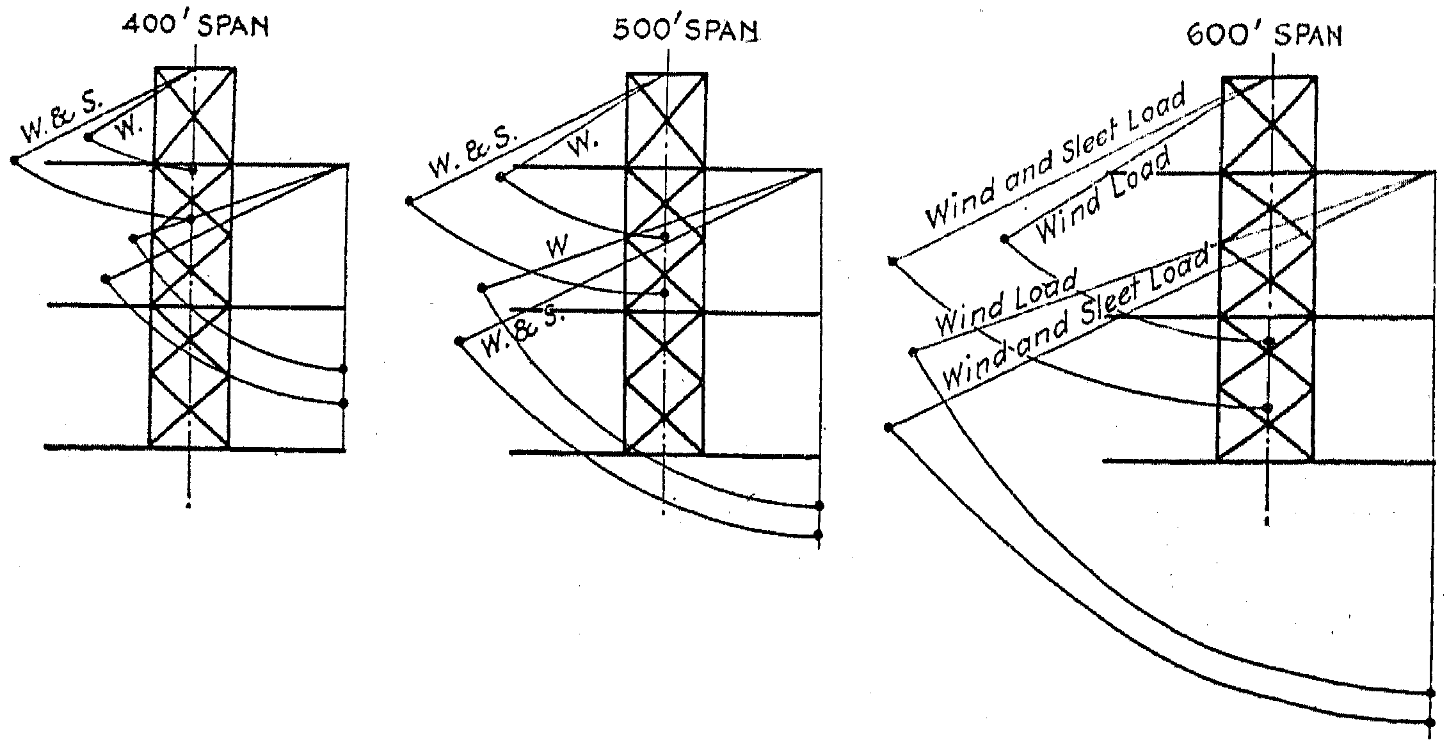


FIG. 54—PENNSYLVANIA WATER AND POWER CO. DEFLECTION OF CABLES FOR TRANSMISSION LINE NO. 1, BALTIMORE

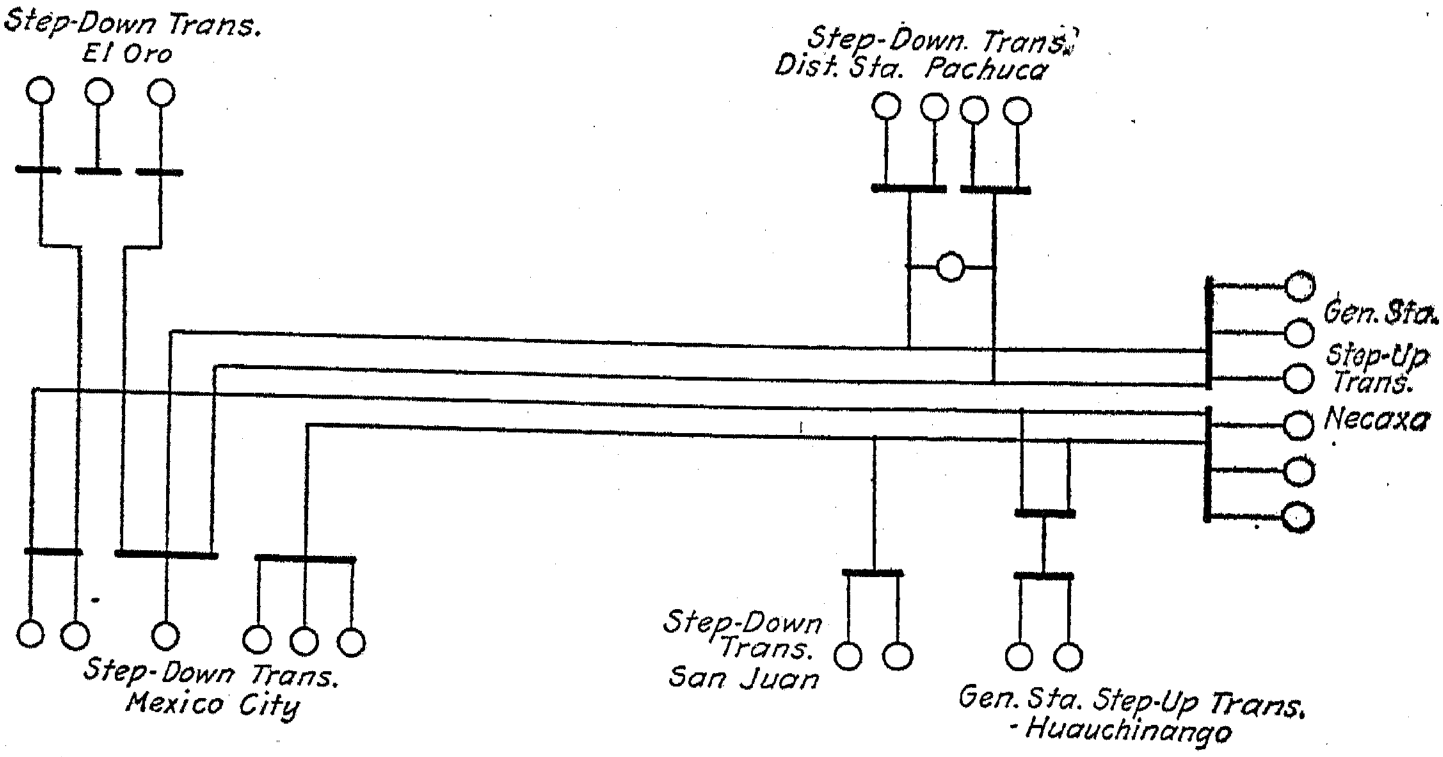


FIG. 55—MEXICAN LIGHT AND POWER CO., LTD. DIAGRAM OF HIGH-TENSION TRANSMISSION LINES

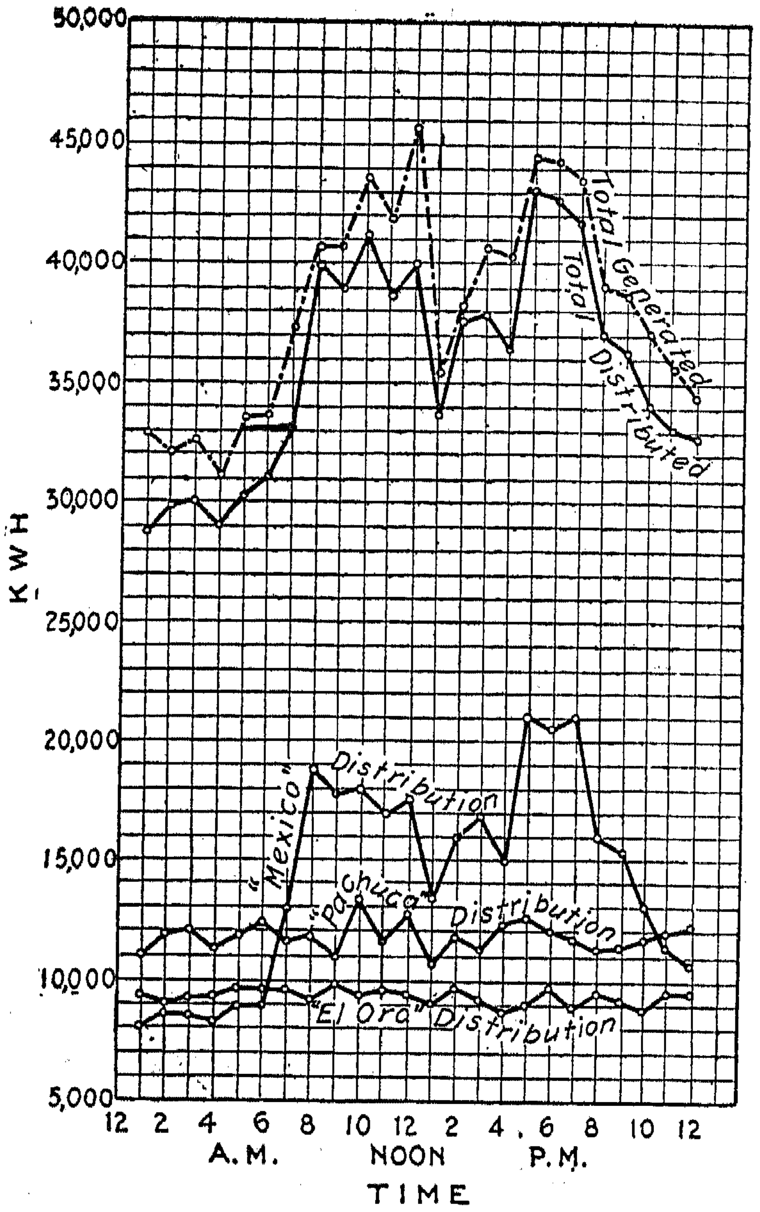


FIG. 56—MEXICAN LIGHT AND POWER CO., LTD. TYPICAL DAILY LOAD CURVE

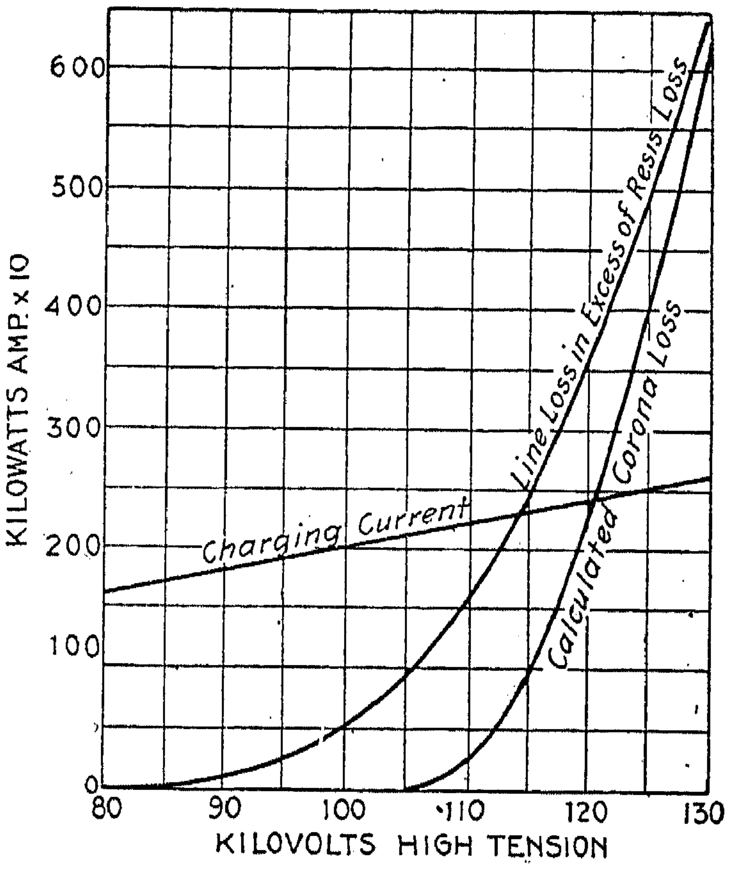


FIG. 57—MISSISSIPPI RIVER POWER CO. LINE CHARGING CHARACTERISTICS AND CORONA LOSSES

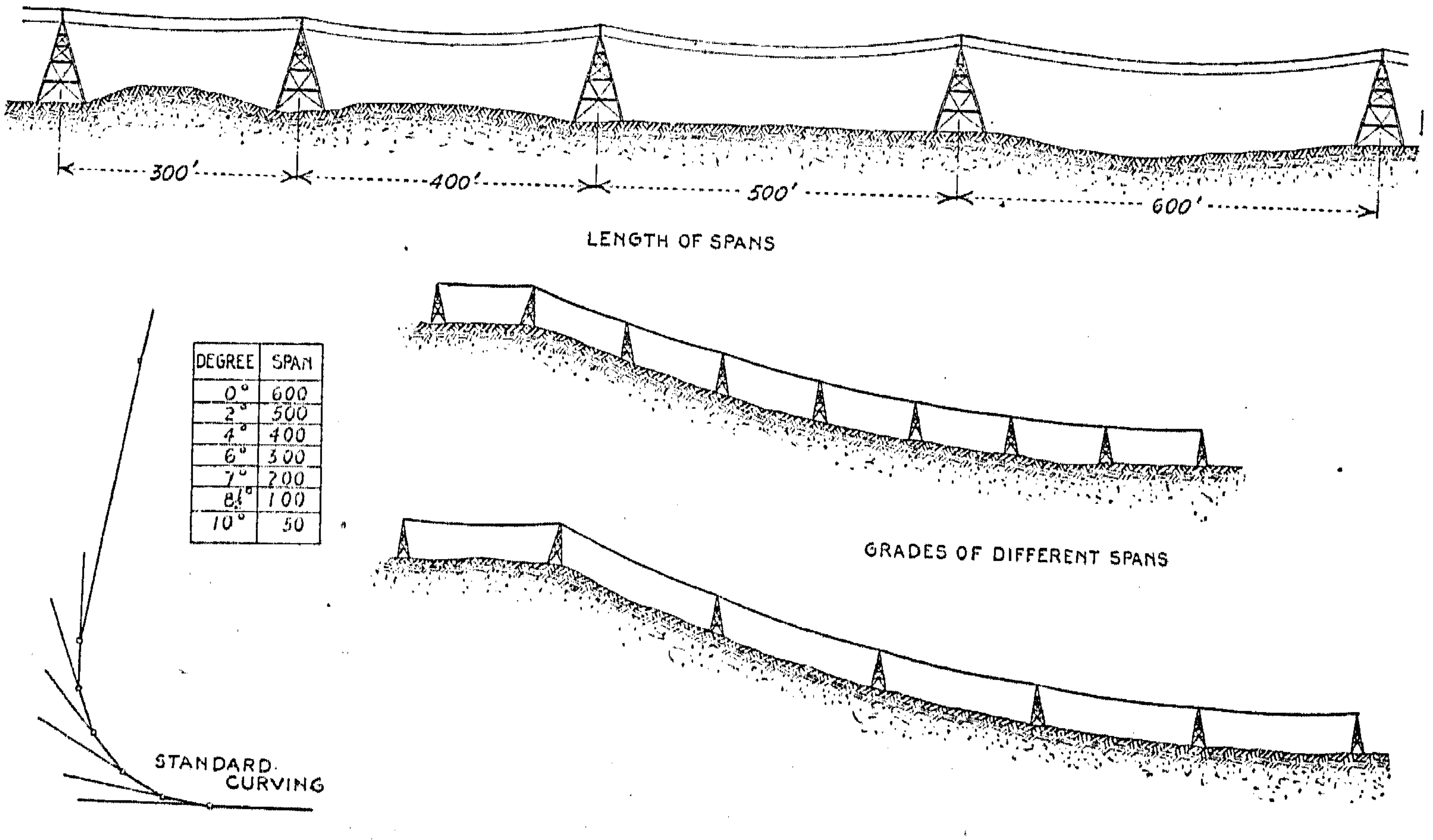


FIG. 58—MEXICAN LIGHT AND POWER CO., LTD., VERTICAL AND HORIZONTAL ANGLES.

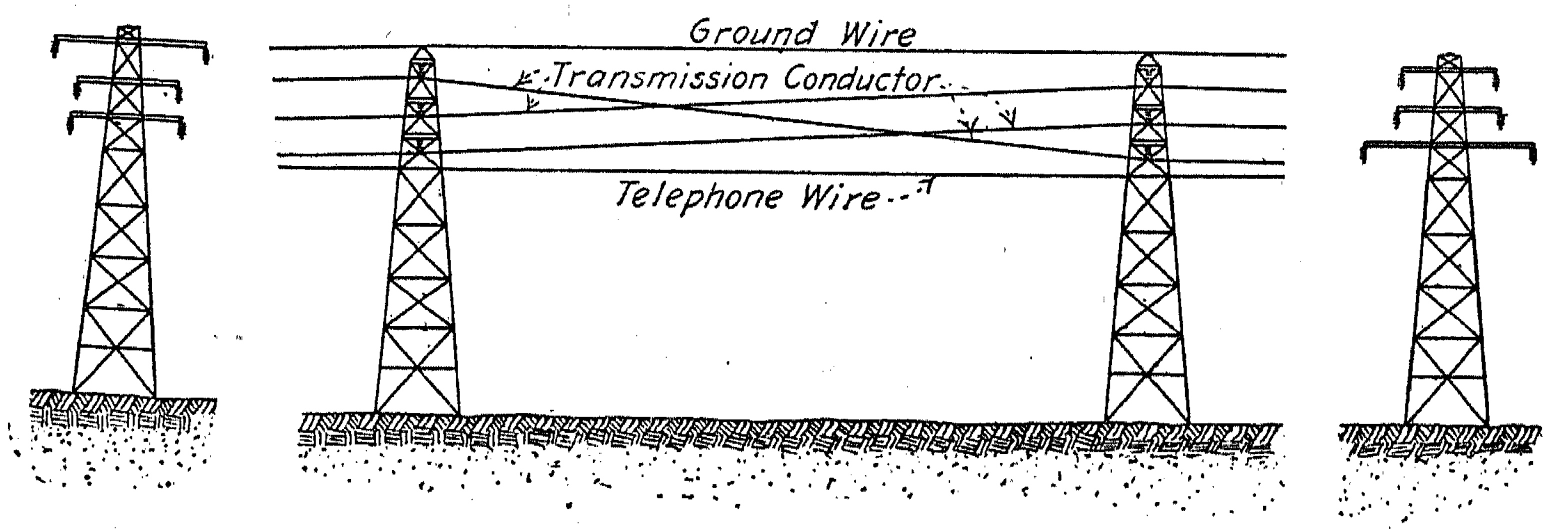


FIG. 59—WASHINGTON WATER POWER CO. TRANSPOSITION

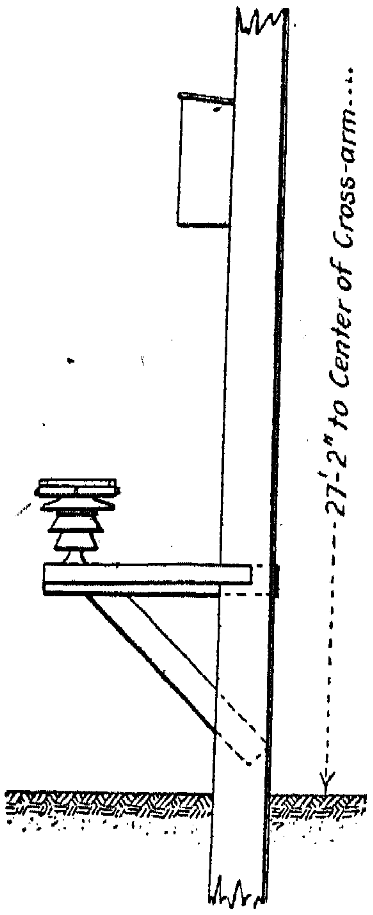


FIG. 60—WASHINGTON WATER POWER CO. DETAIL OF TELEPHONE INSULATING STAND FOR LINEMAN

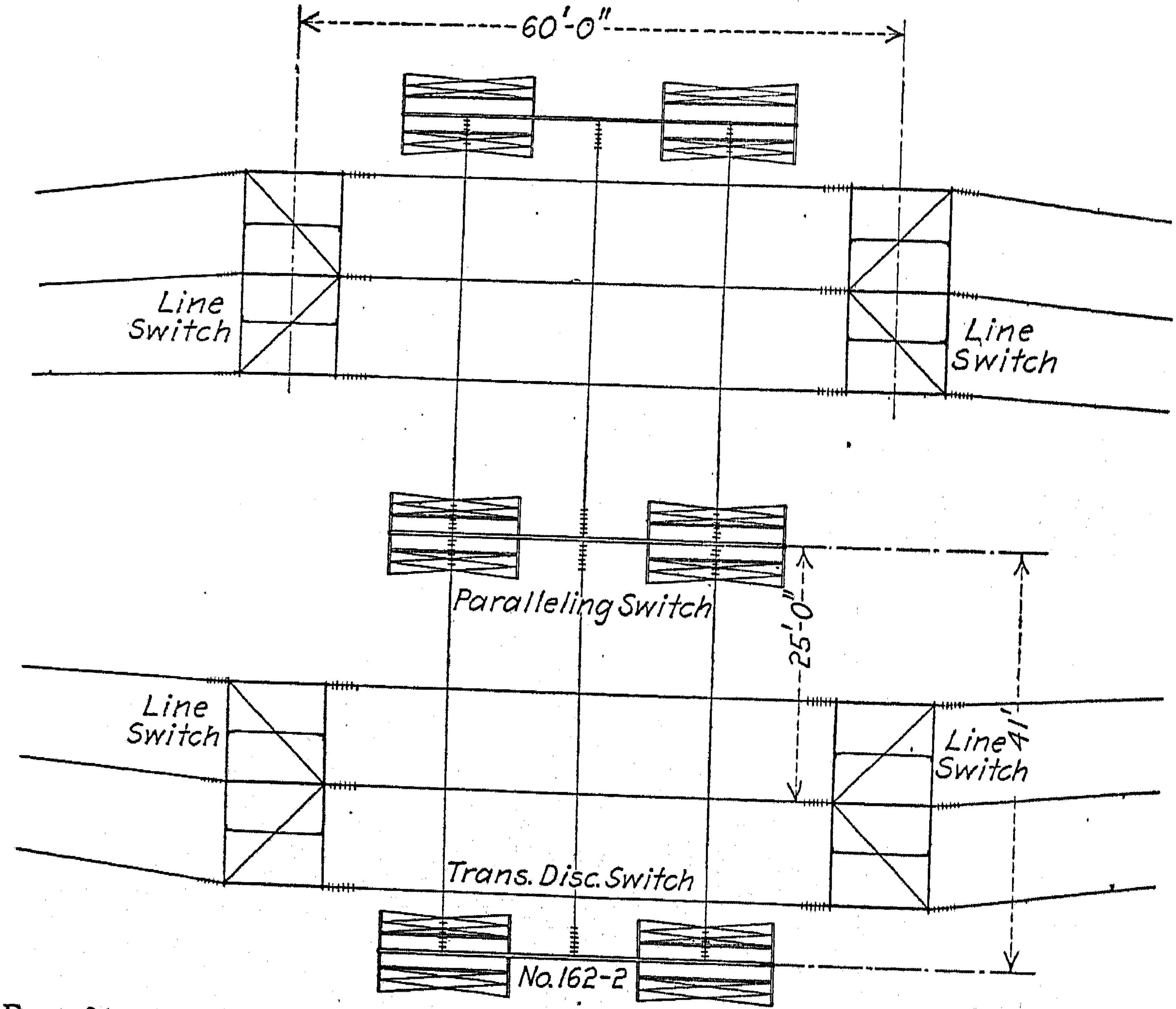


FIG. 61—SOUTHERN SIERRAS POWER CO. DIAGRAM OF SWITCHING STATION

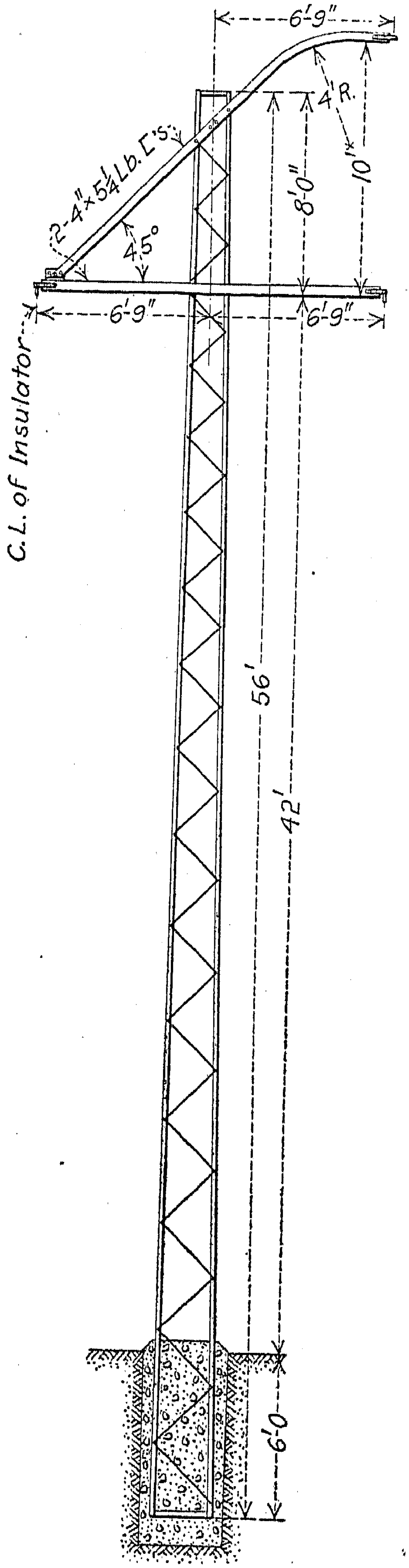


Fig. 62—Southern Sierras Power Co.
Detail of 56-Ft. Steel Pole

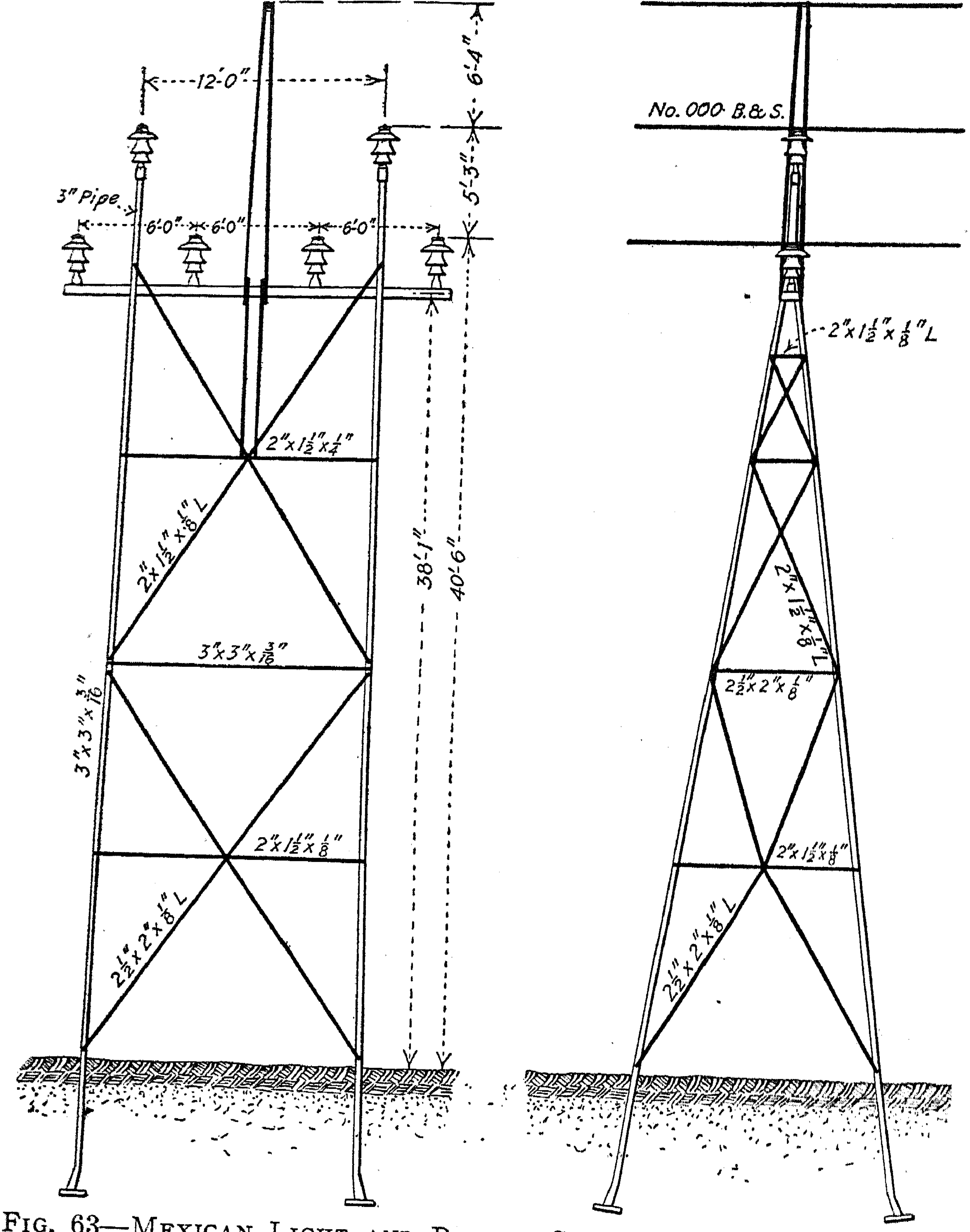


Fig. 63—Mexican Light and Power Co., Ltd. Construction of Standard Towers

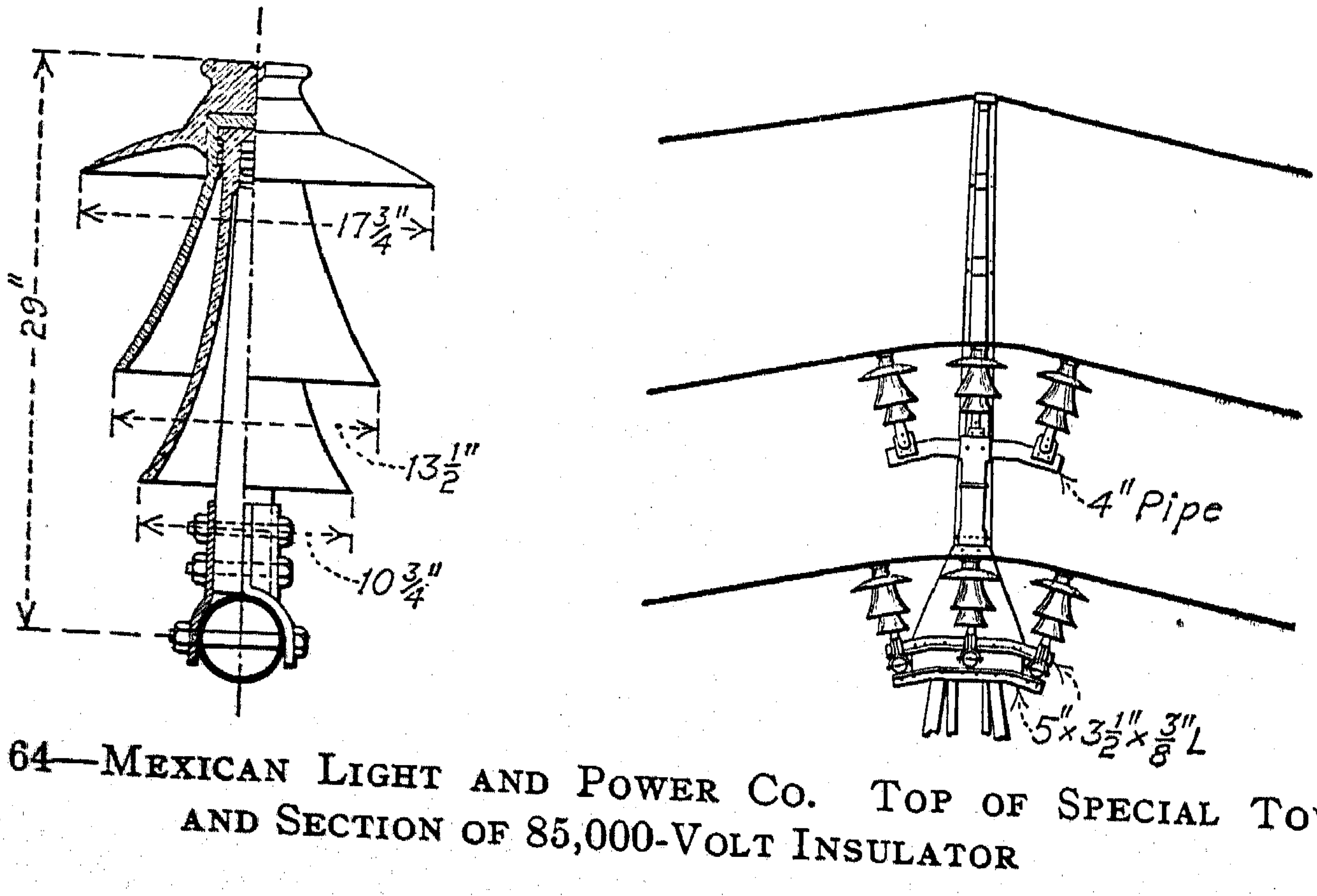


Fig. 64—Mexican Light and Power Co. Top of Special Tower and Section of 85,000-Volt Insulator

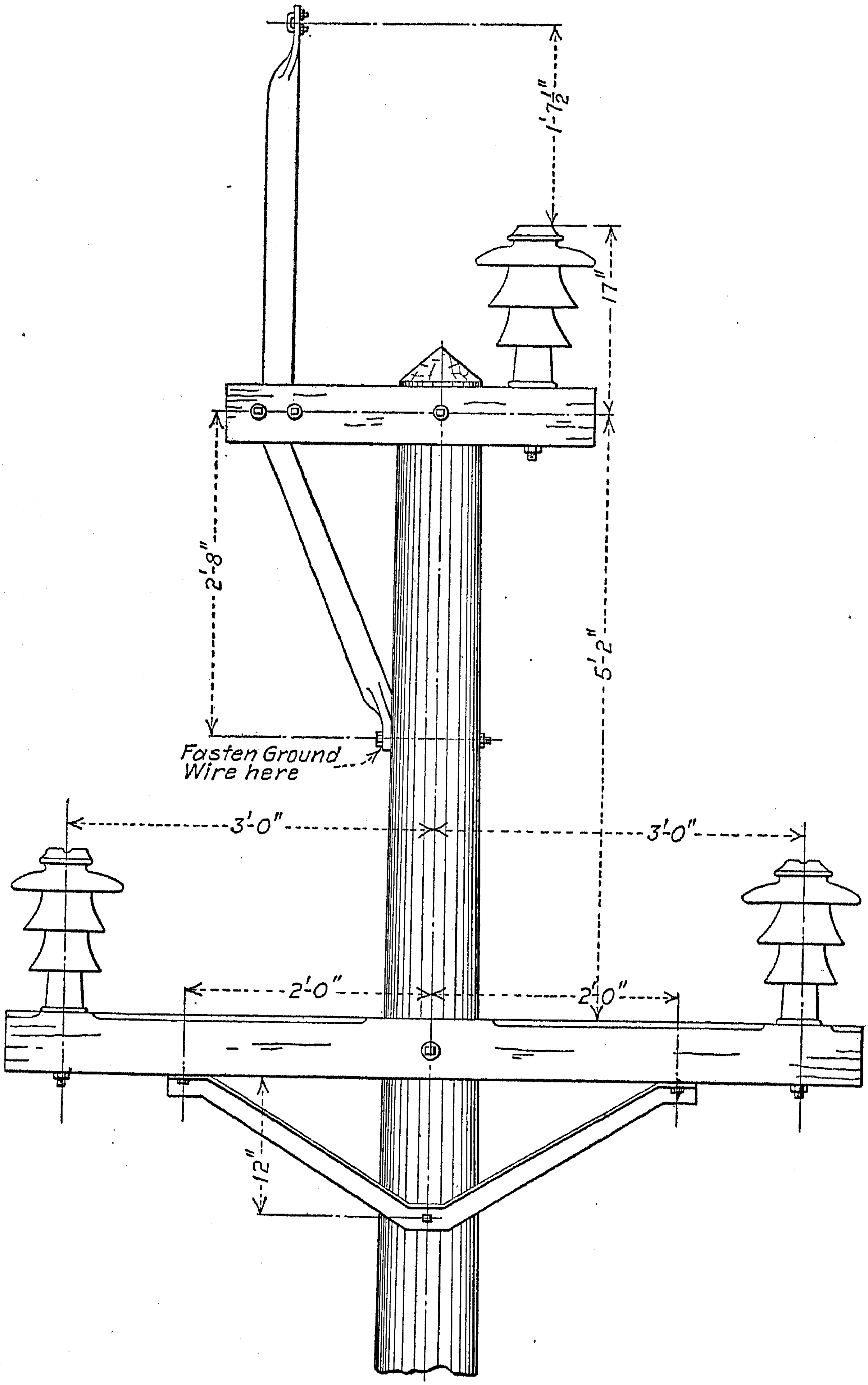


FIG. 65—" X." DETAIL OF POLE TOP—50,000-VOLT SINGLE-CIRCUIT TRANSMISSION LINE

APPENDIX

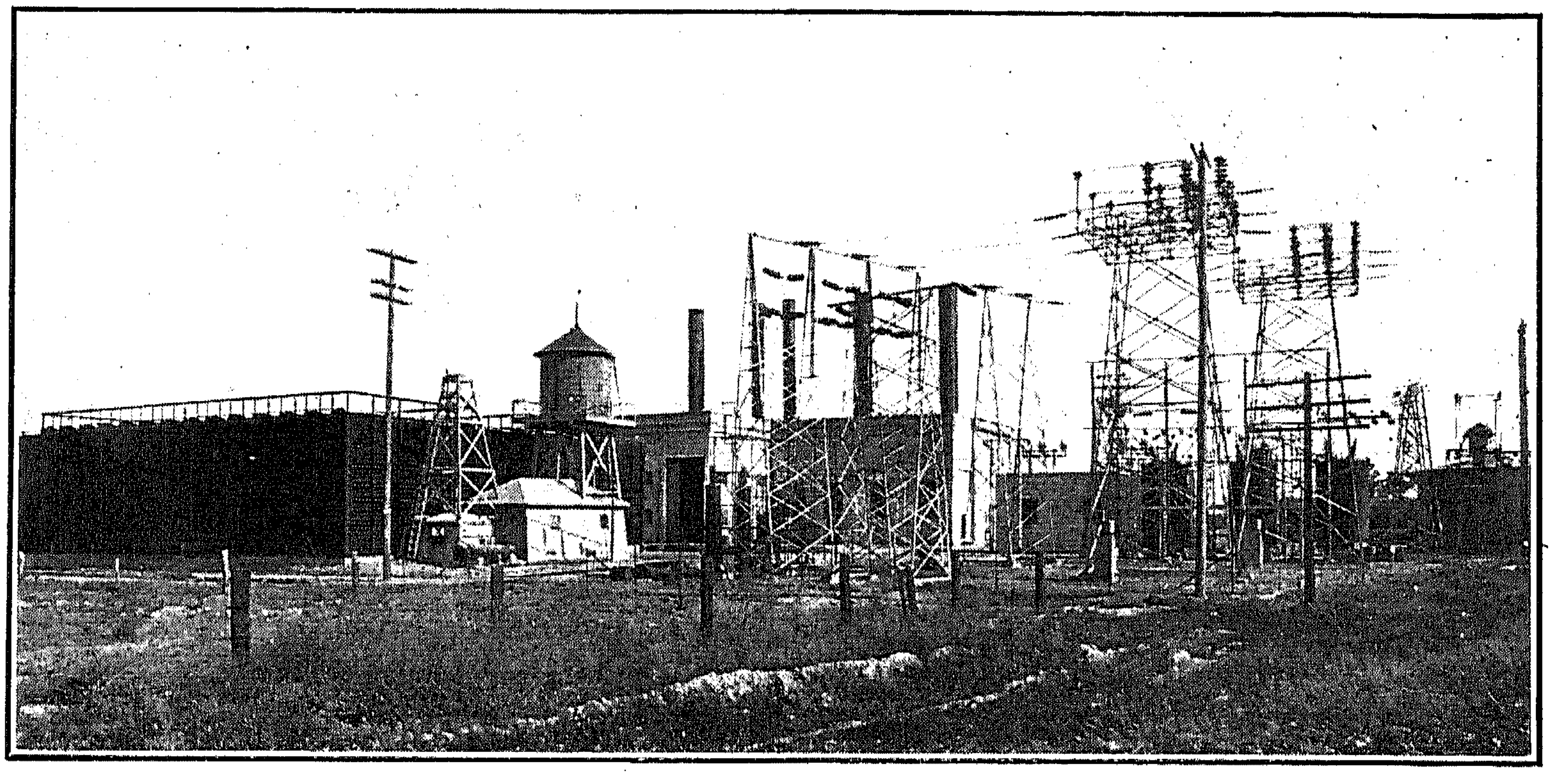
Following is the list of questions submitted to high-tension operating companies from which the answers to the foregoing data have been compiled.

A

THE LINE AS A STRUCTURE.

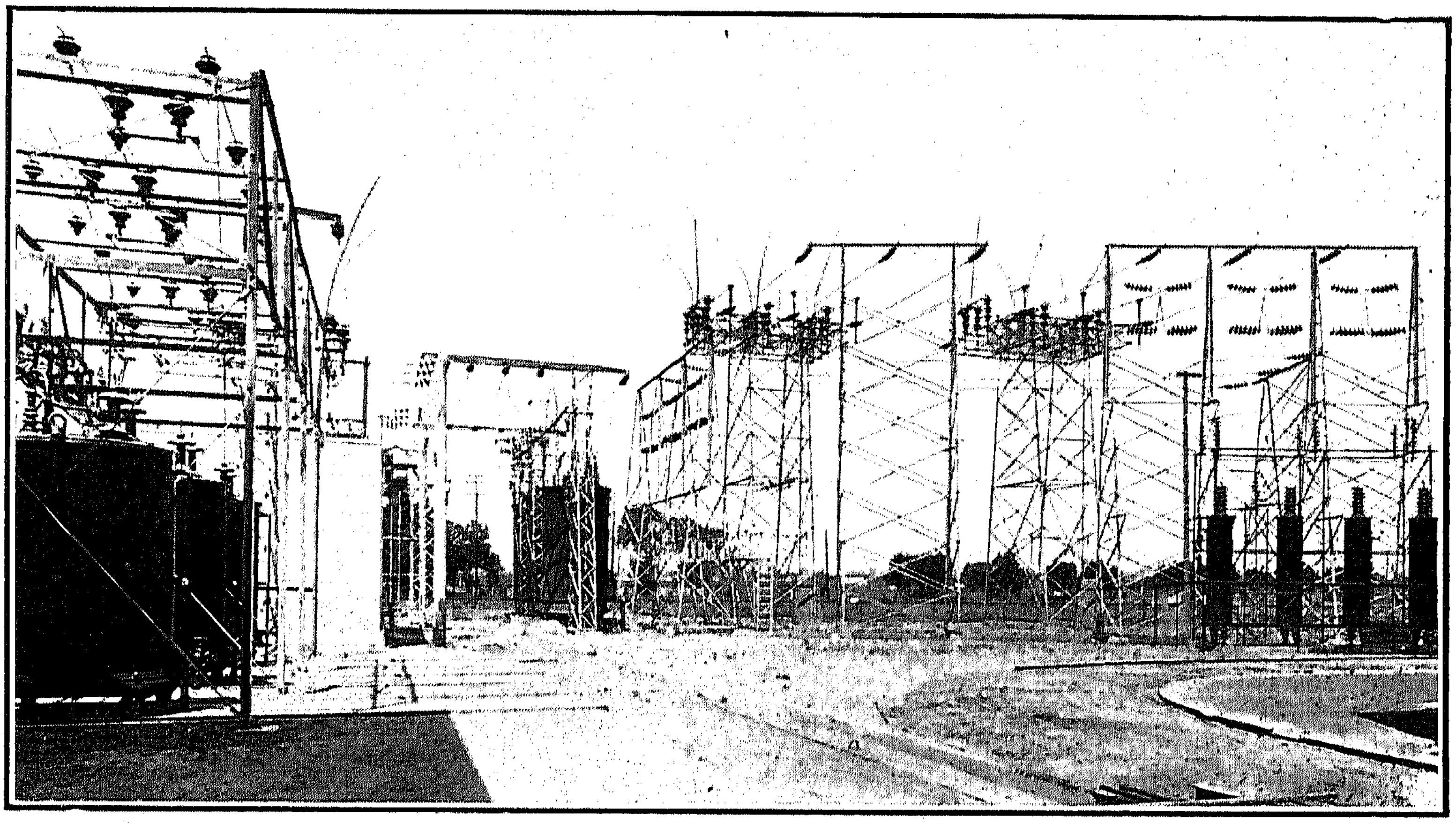
ONLY SYSTEMS OF 25,000 VOLTS OR HIGHER

1. Outline drawings of your standard high-tension lines. Side view of span and a view at the tower looking along the line.
2. Give height of pole or tower, dimensions and locations of crossarms and position of wires, distance between two circuits on same towers, foundations, show all overhead grounded wires, etc. Attach sketches hereto. Also give:
3. Total length of main line. Altitude. General air temperature range.
4. Size and material of conductor, core, if any, etc.
5. Length of standard span.
6. Sag is at temperature of deg. cent.
7. Manufacturer and manufacturer's catalogue number of high-tension line insulator.
8. Material of insulator.
9. Standard clearance above ground at middle of span.
10. Minimum clearance above roadways. Over railways.
11. Details of pin construction.
12. Form of strain insulators. (Sketch preferred, with catalogue number and make of insulator.)
13. How many units in series?
14. Dry test given standard line insulator.
15. Dry test given strain insulator.
16. Wet test given line insulator.
17. Wet test given strain insulator.
18. How is the "loop" in the conductor around the strain insulators at an anchor tower made?
19. Describe fully any exceptionally long spans, and attach description hereto.
20. Describe any special features of line construction having particular interest.
21. Describe method of turning angle, horizontal or vertical, or main line.
22. Describe and show sketch of outlets from buildings for high-tension wires.
23. How are steel towers grounded?
24. Where systems at different voltages are connected together on the high-tension side, are auto-transformers, or separate coil transformers, used?
25. What sorts of deterioration do you observe in the conductor, insulators or towers after long service?



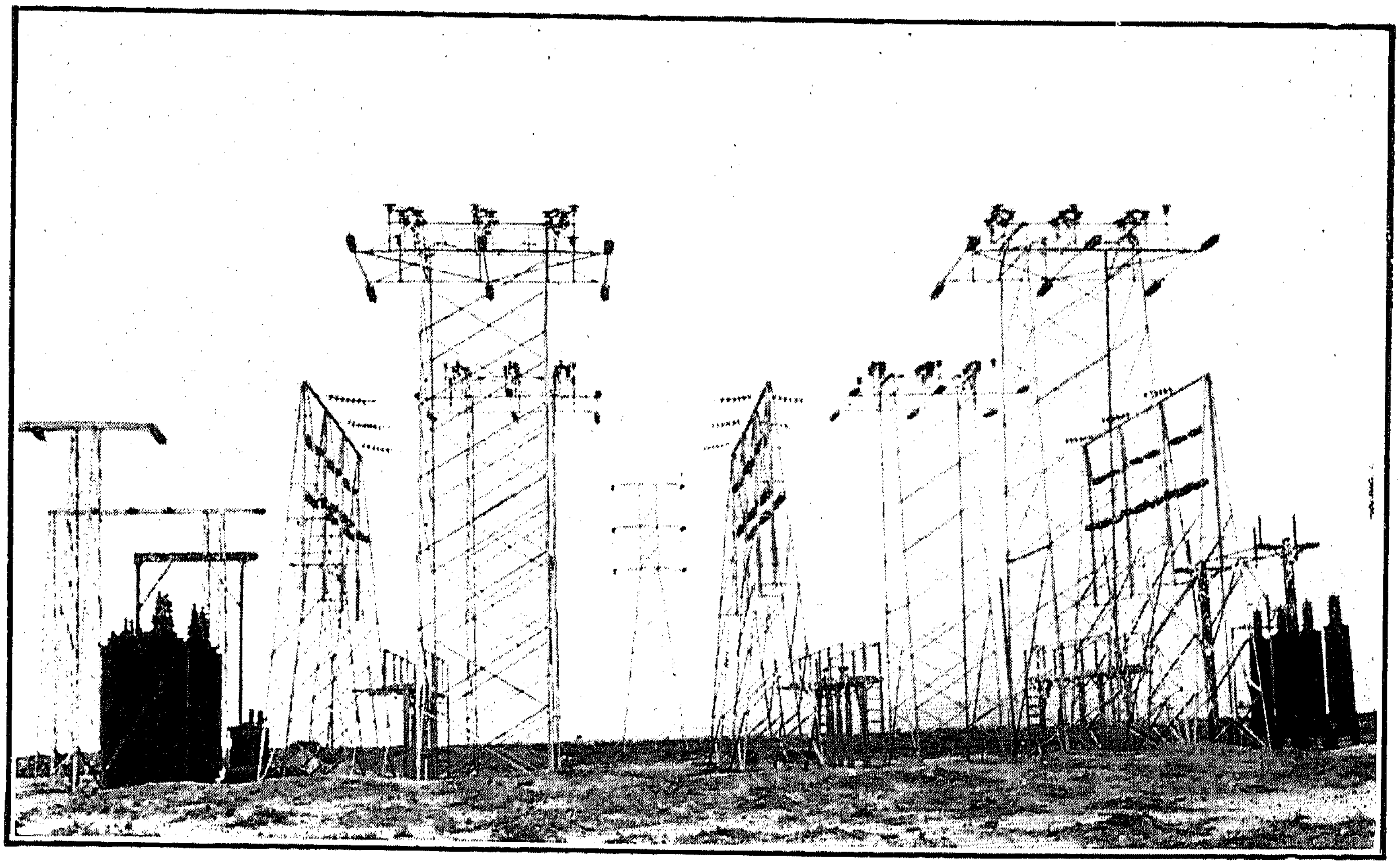
[THOMAS]

FIG. 66—SOUTHERN SIERRAS POWER CO. SAN BERNARDINO OUTDOOR TRANSFORMER STATION



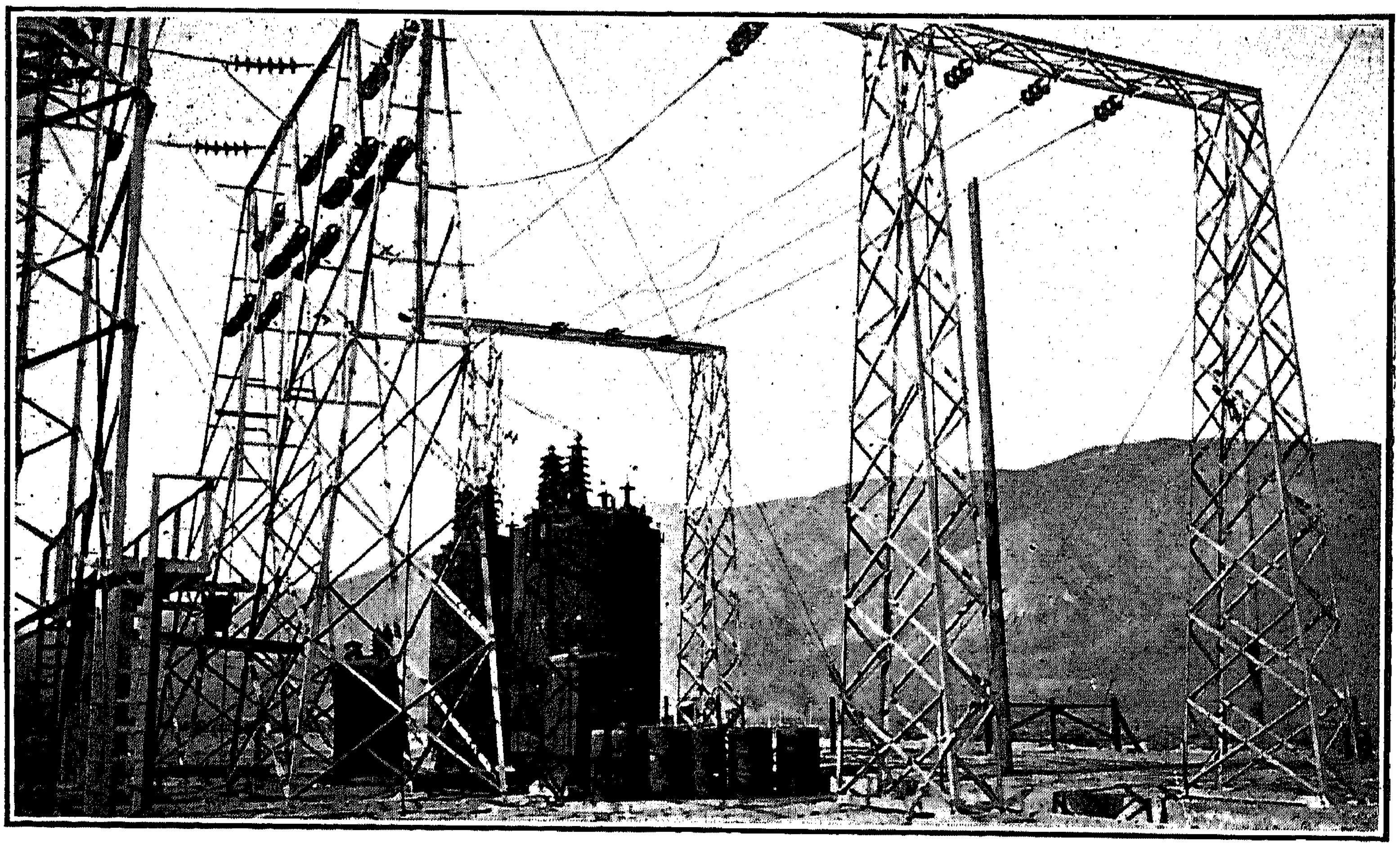
[THOMAS]

FIG. 67—SOUTHERN SIERRAS POWER CO. OUTDOOR TRANSFORMER STATION AT THE SAN BERNARDINO GENERATING PLANT



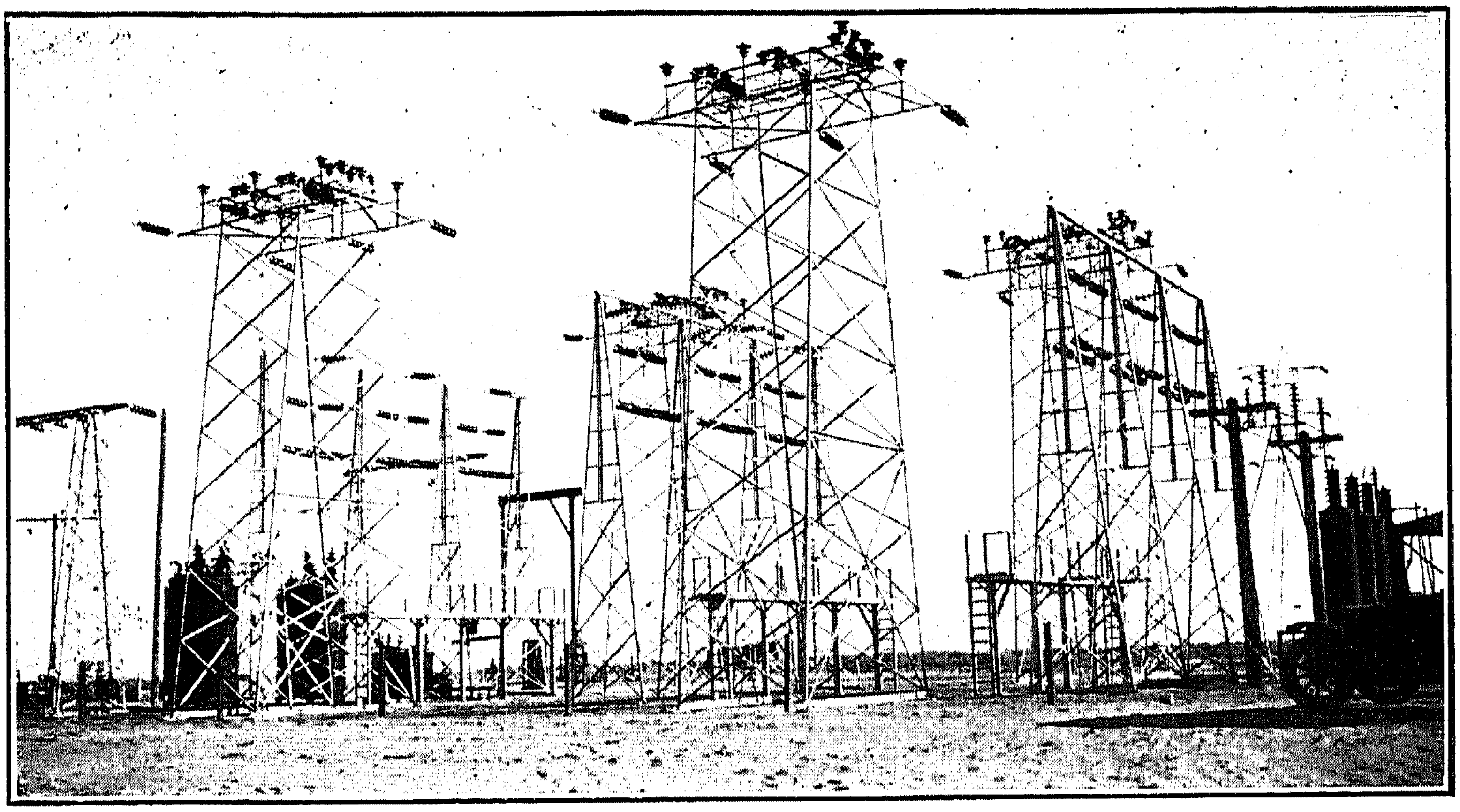
[THOMAS]

FIG. 68—SOUTHERN SIERRAS POWER CO. LONE PINE SUBSTATION—60,000-VOLT NON-AUTOMATIC CIRCUIT BREAKERS.



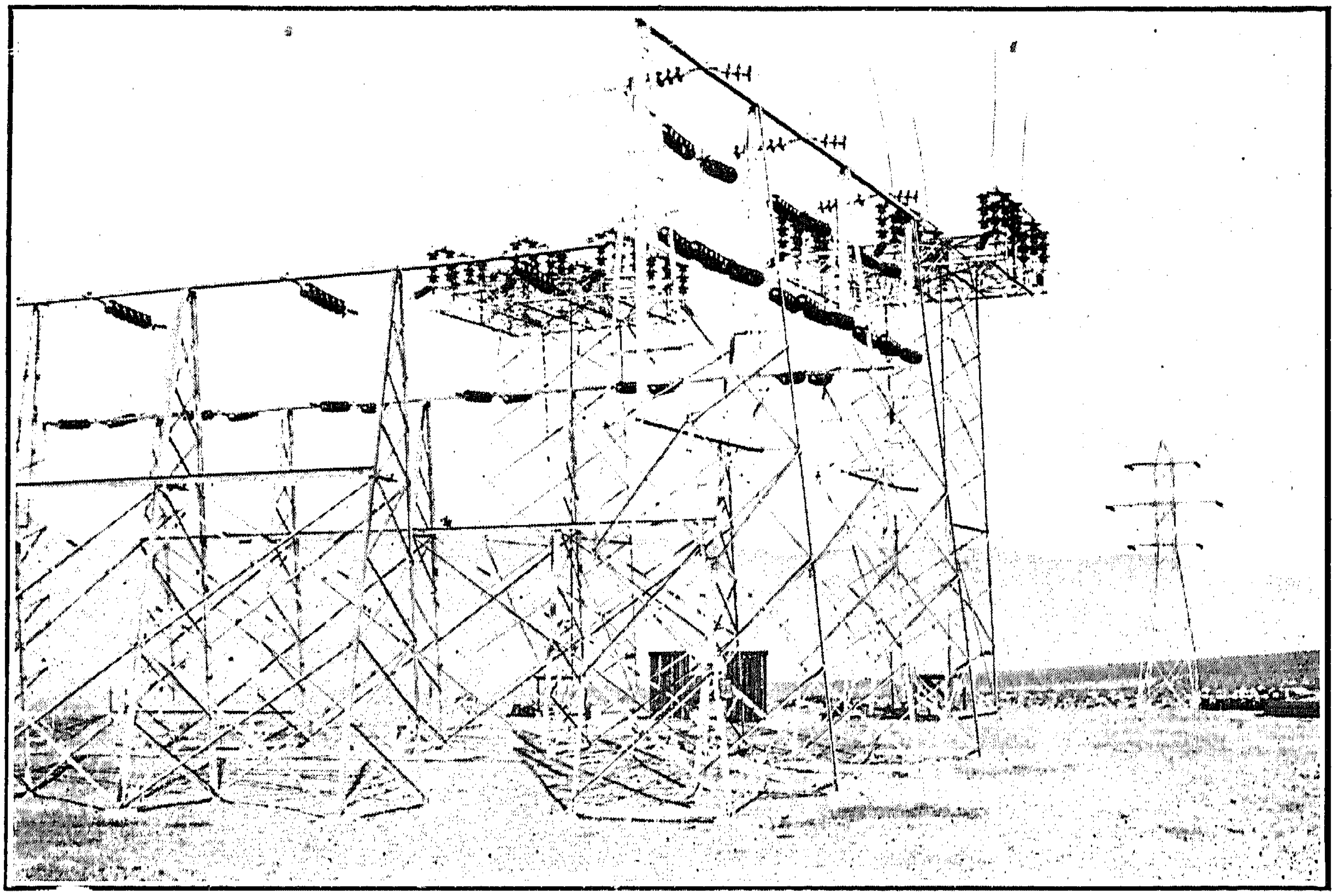
[THOMAS]

FIG. 69—SOUTHERN SIERRAS POWER CO. LONE PINE SUBSTATION



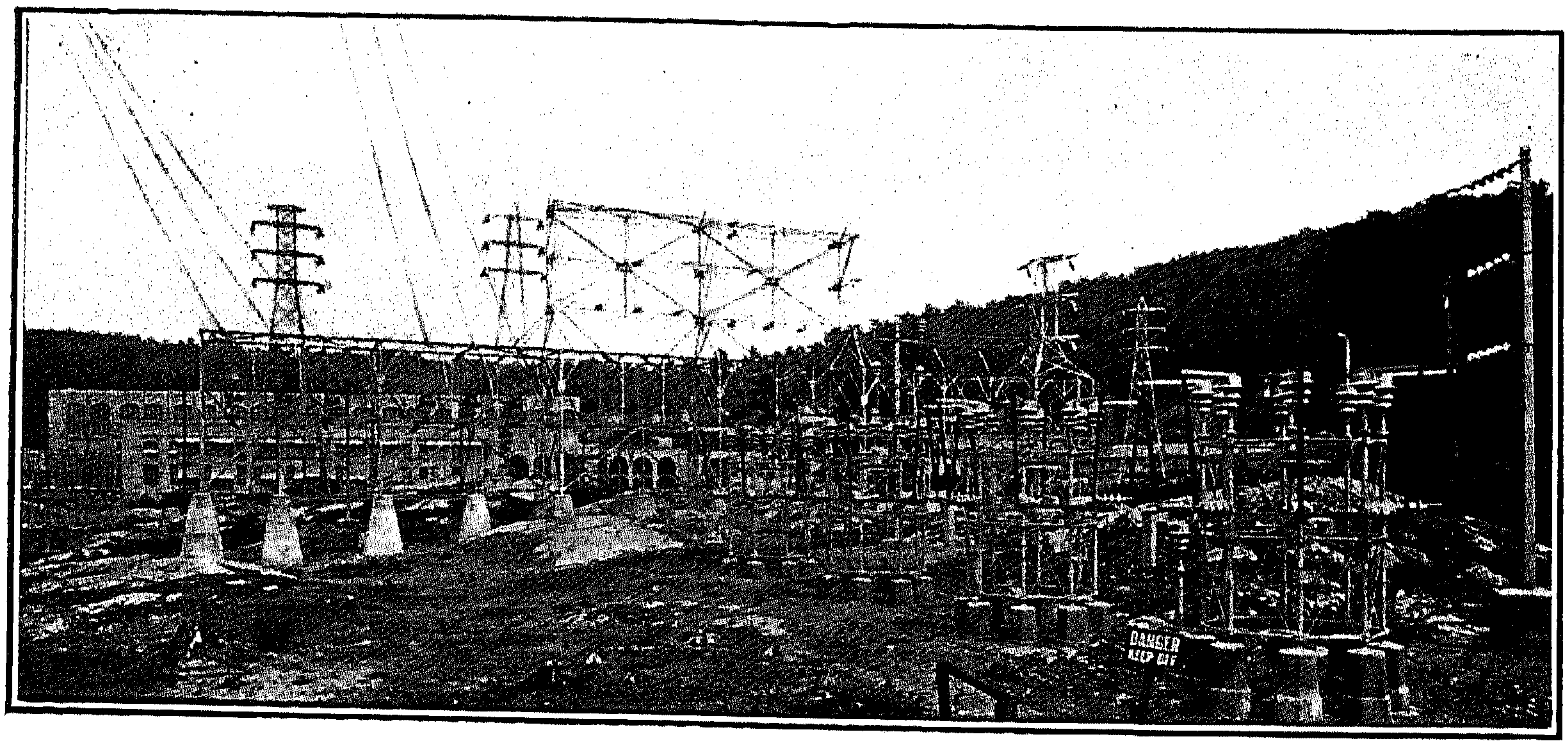
[THOMAS]

FIG. 70—SOUTHERN SIERRAS POWER CO. VIEW OF SUBSTATION AT LONE PINE



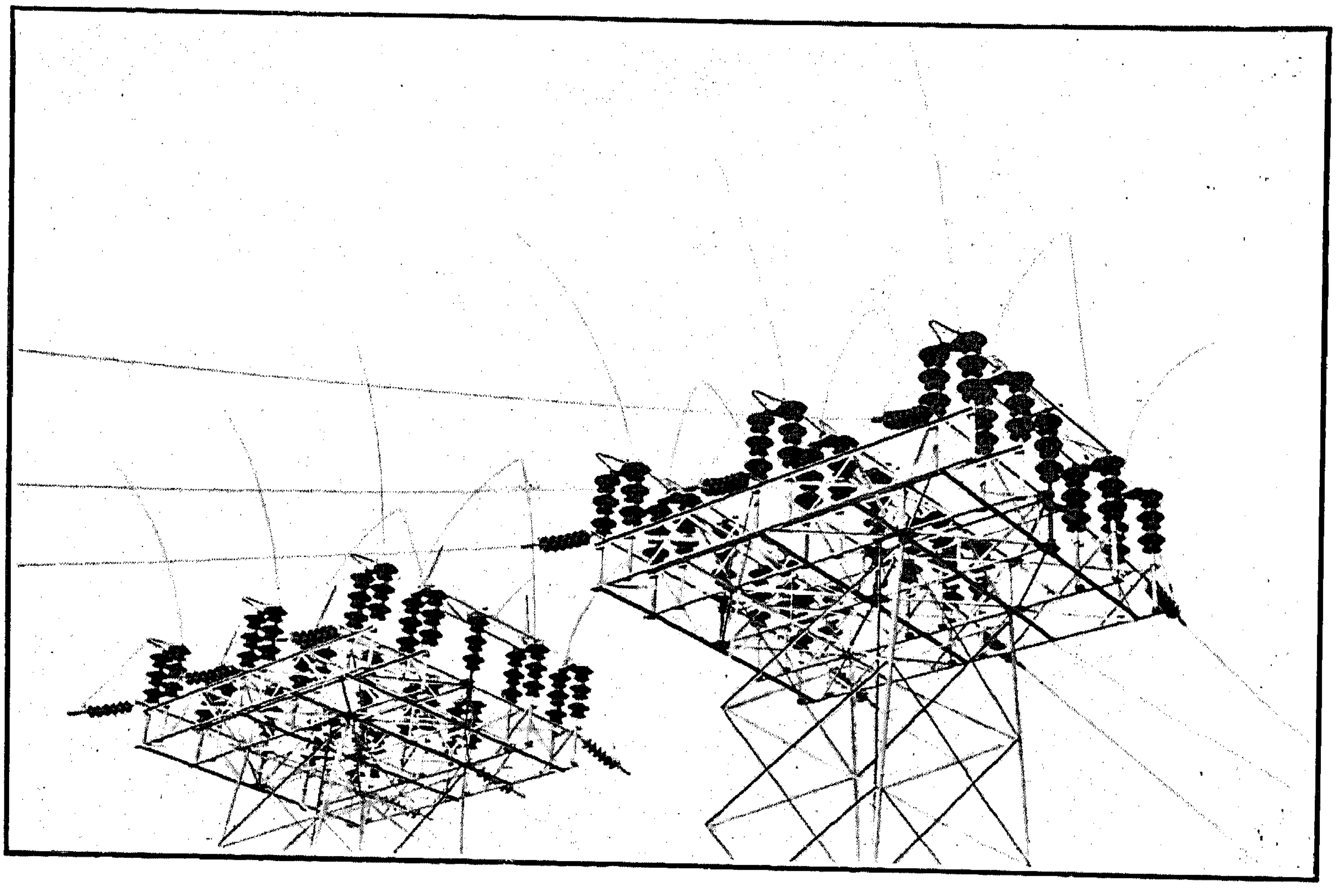
[THOMAS]

FIG. 71—SOUTHERN SIERRAS POWER CO. CONTROL STATION NEAR MOUTH OF BISHOP CREEK CANYON—COMMENCEMENT OF TRANSMISSION TO SAN BERNARDINO



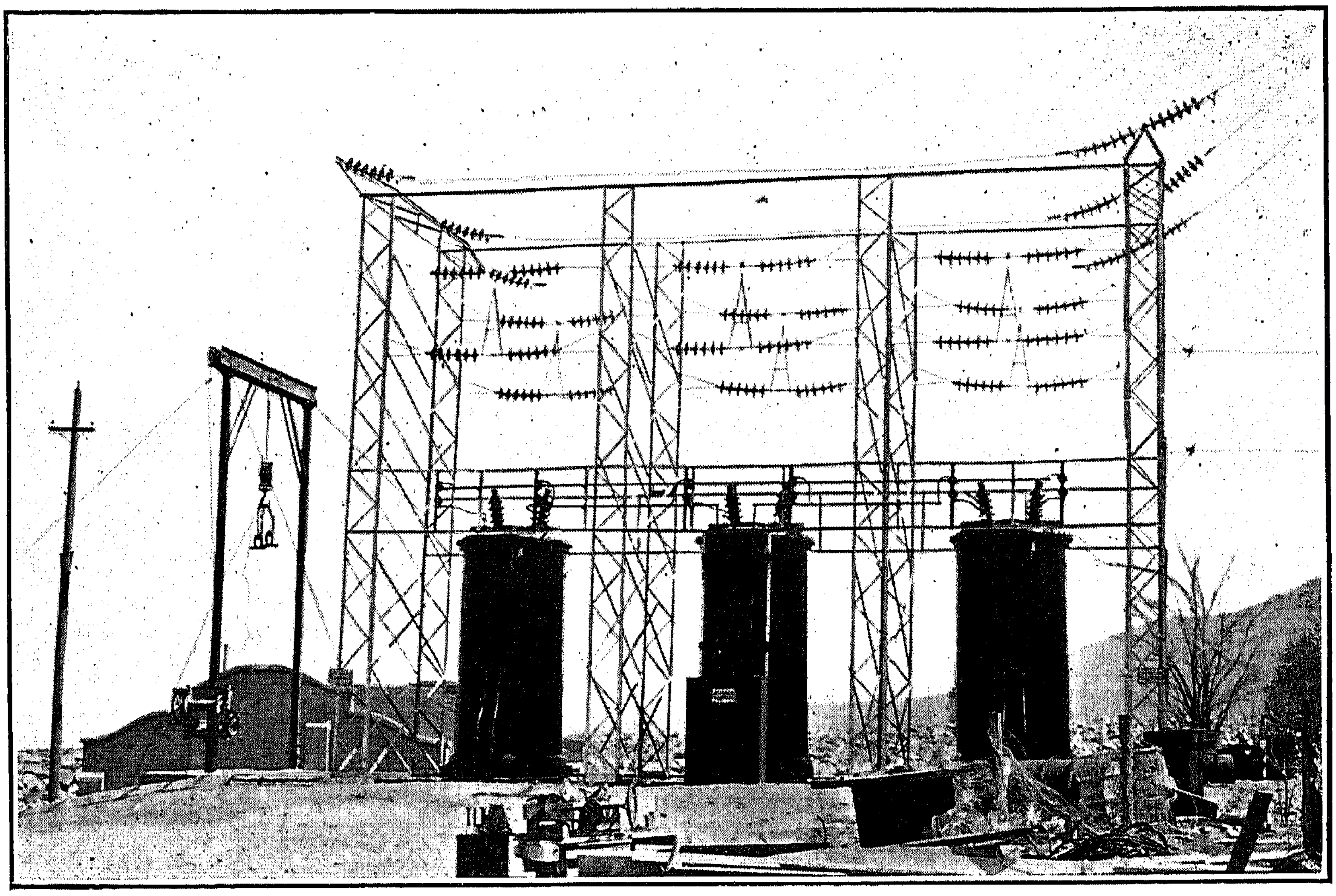
[THOMAS]

FIG. 72—PENNSYLVANIA WATER AND POWER CO. NICHOLSON'S LIGHTNING ARRESTERS



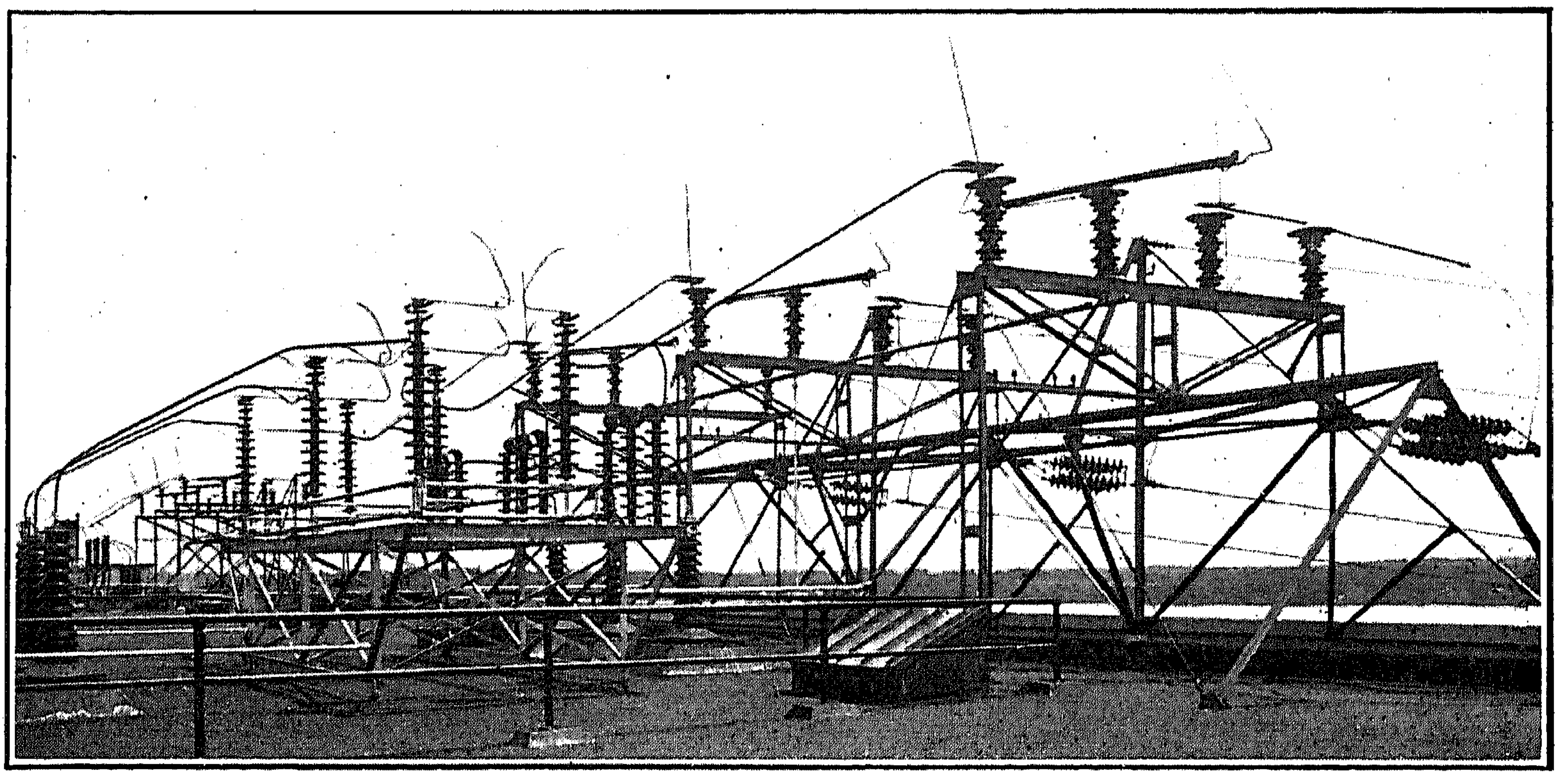
[THOMAS]

FIG. 73—SOUTHERN SIERRAS POWER CO. CONTROL STATION AT BISHOP, SHOWING DOUBLE BREAK, PNEUMATICALLY-OPERATED, SYNCHRONIZING CIRCUIT BREAKERS



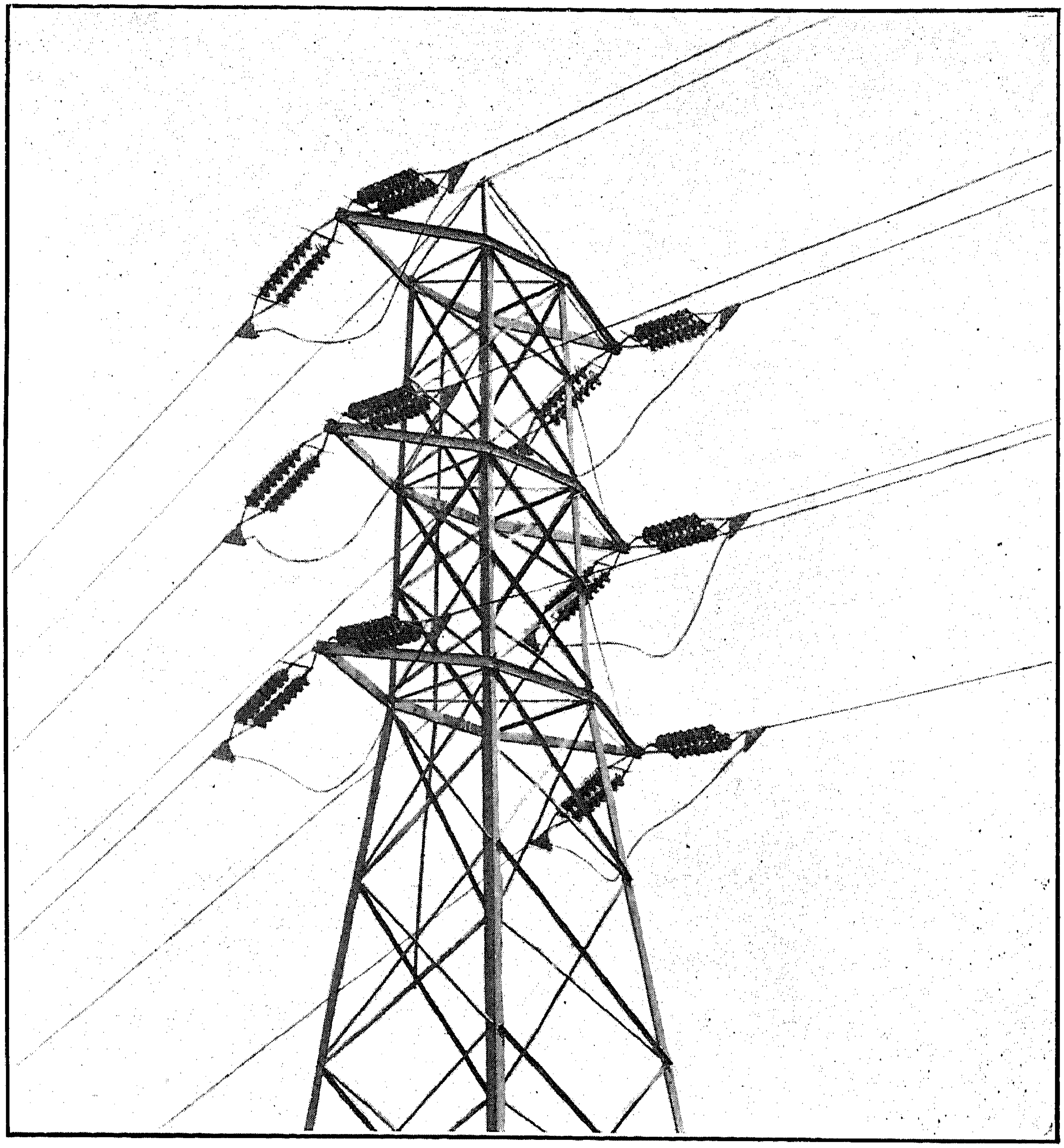
[THOMAS].

FIG 74—SOUTHERN SIERRAS POWER CO. TRANSFORMER STATION, POWER PLANT NO. 6



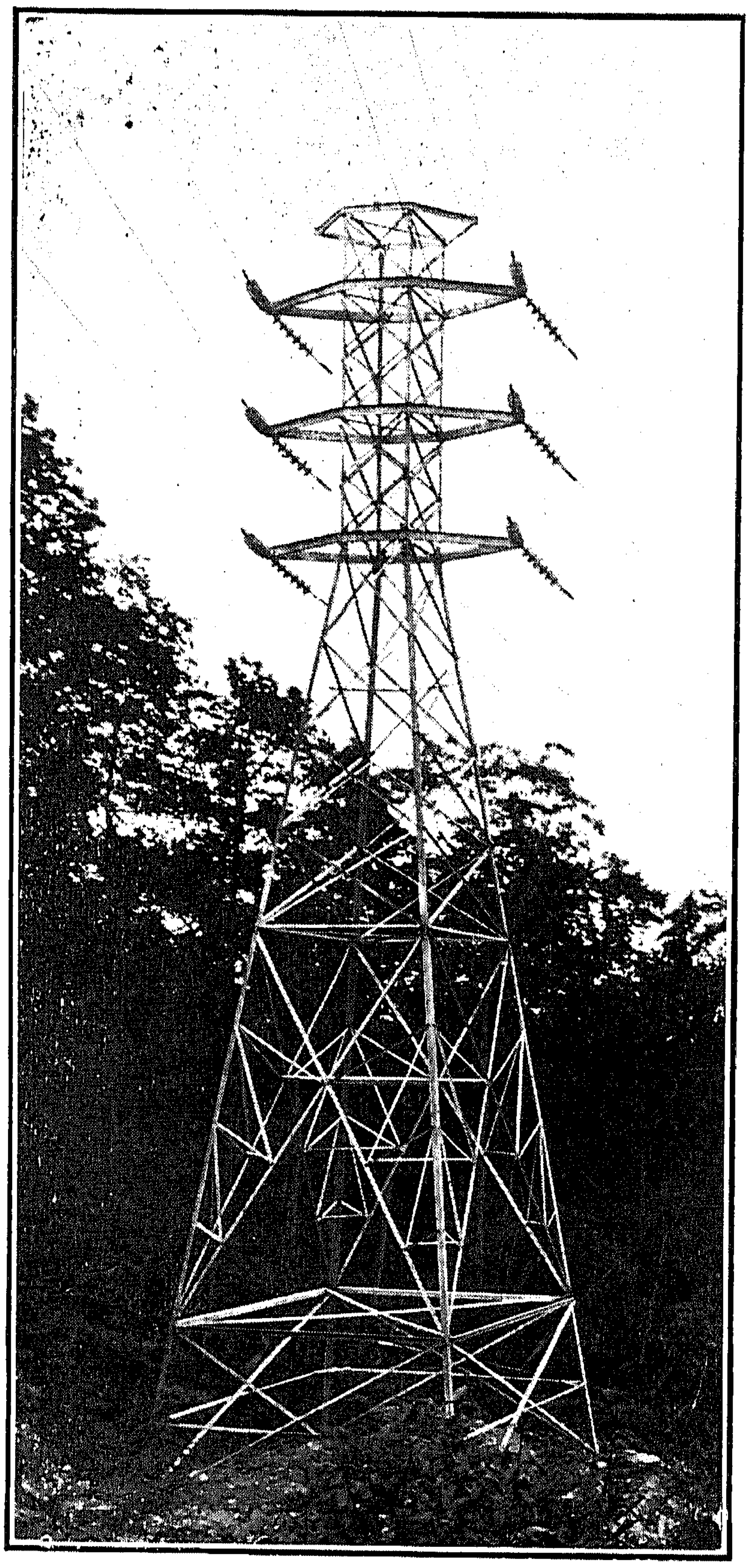
[THOMAS]

FIG. 75—MISSISSIPPI RIVER POWER CO. ROOF STRUCTURES FOR 110,000-VOLT LINE ENTRANCE

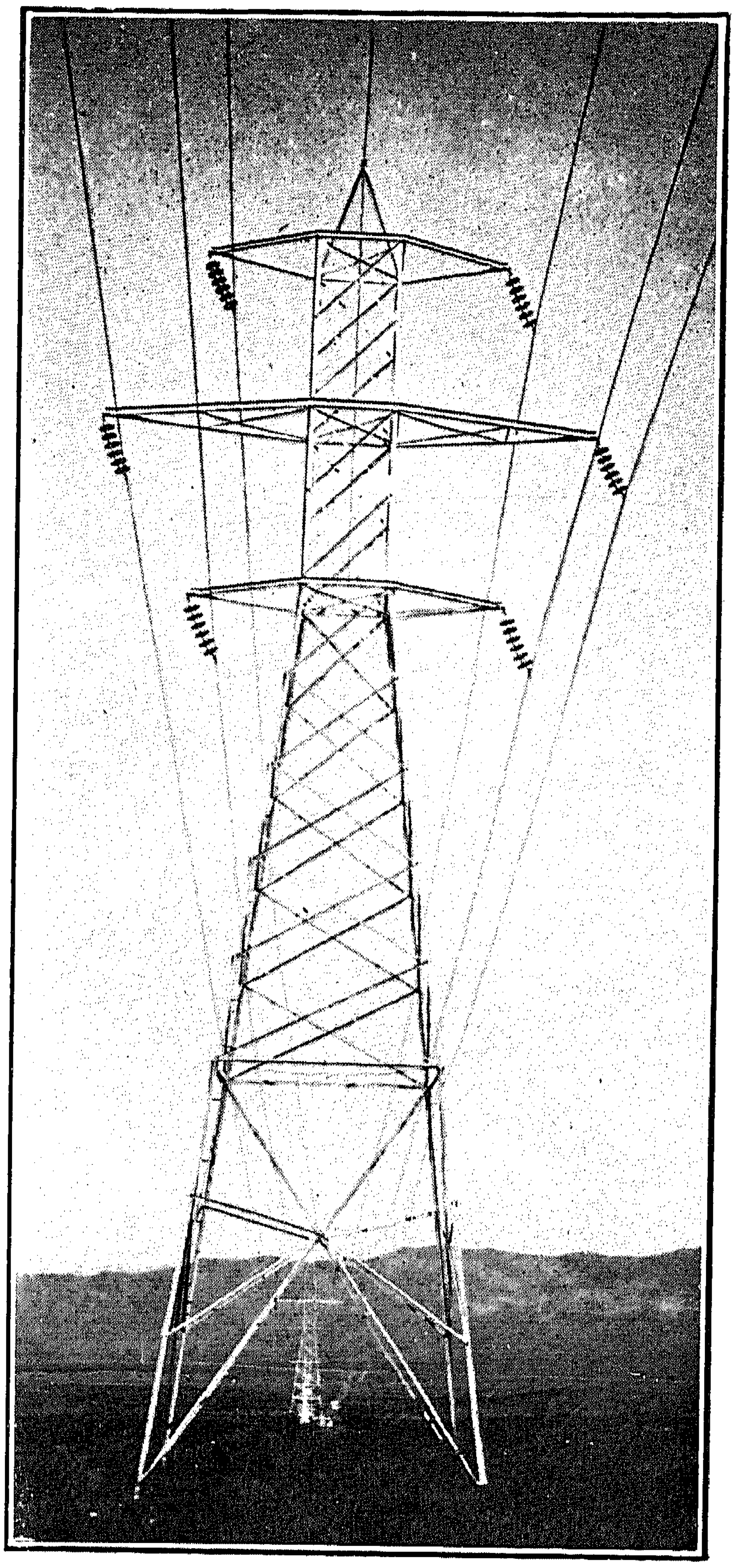


[THOMAS]

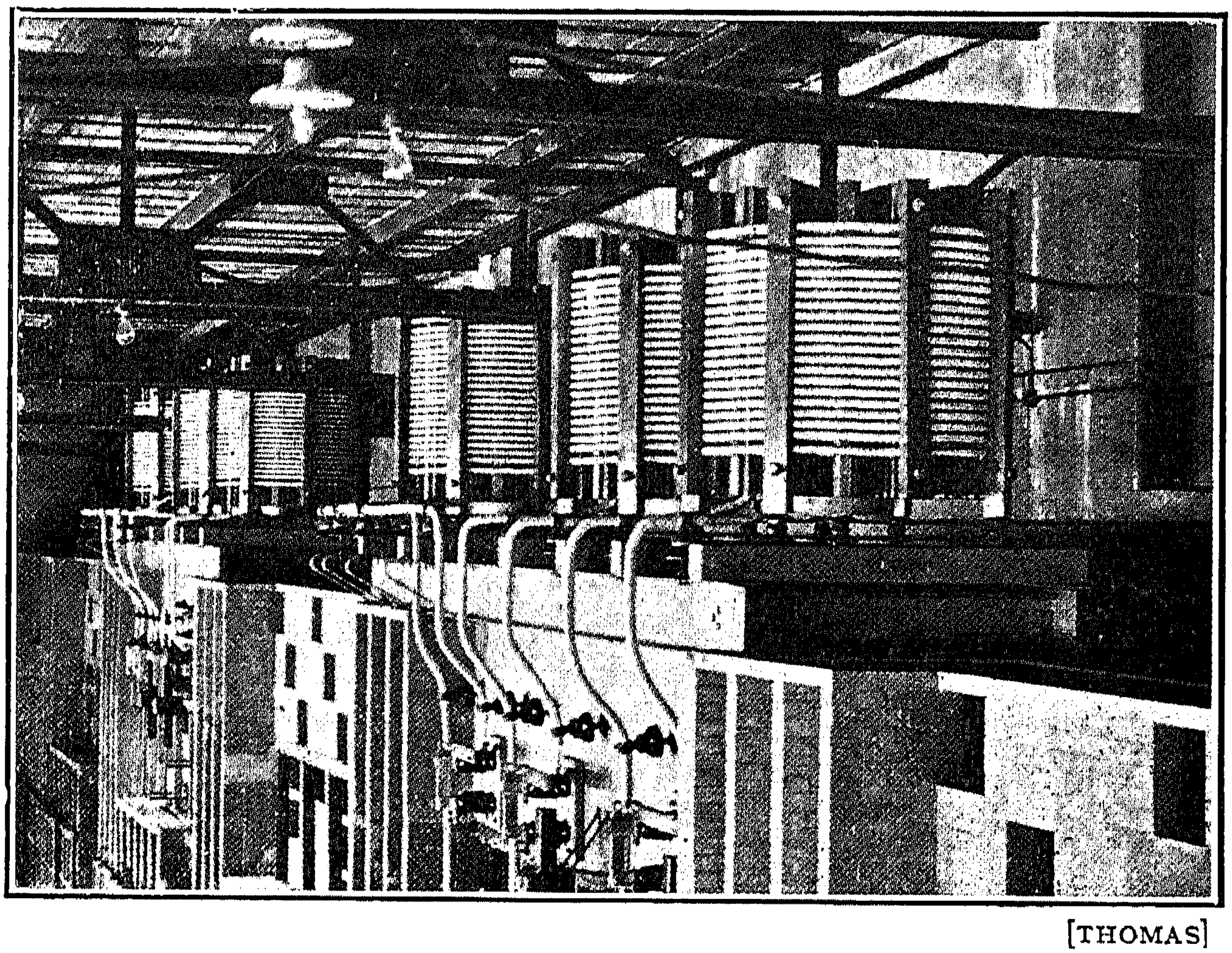
FIG. 76—MISSISSIPPI RIVER POWER CO. TURN IN LINE AT TOWER NO. 12



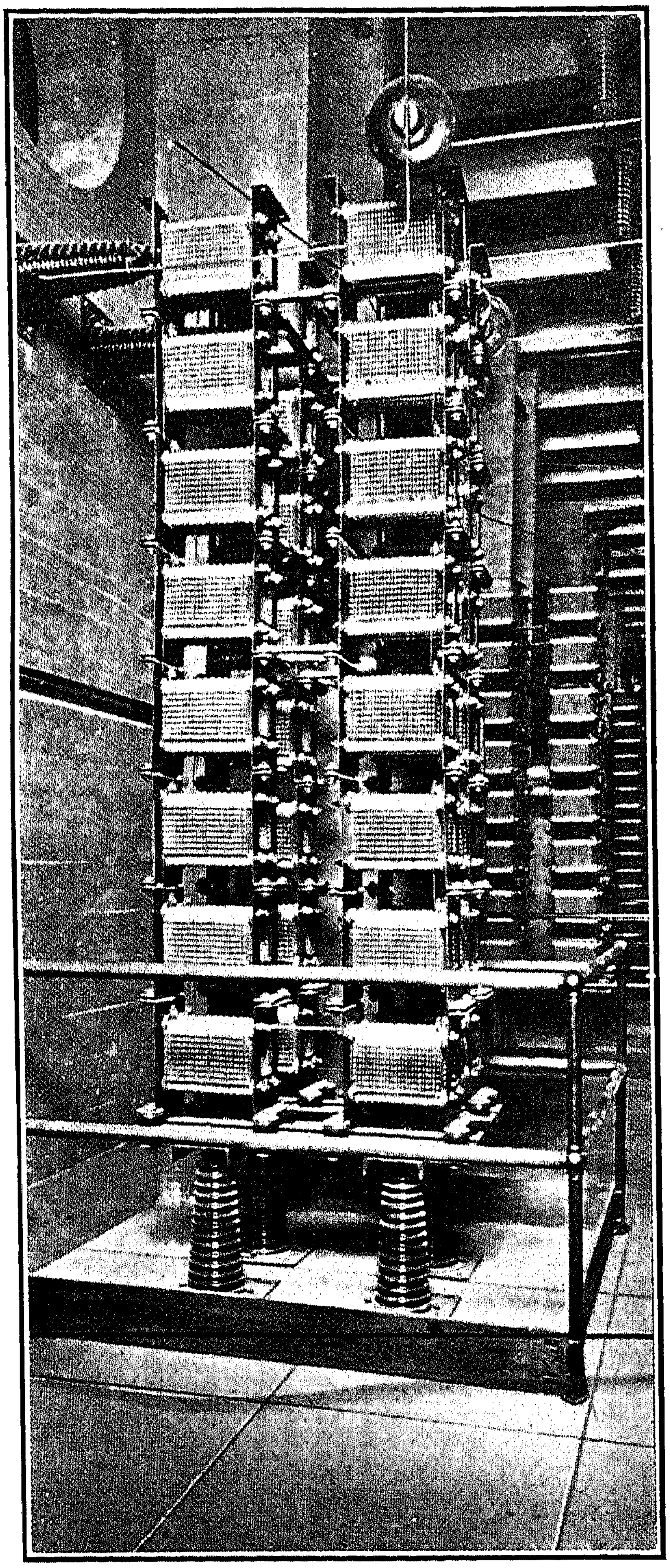
[THOMAS]
FIG. 77—PENNSYLVANIA WATER AND POWER CO. STANDARD ANGLE TOWER



[THOMAS]
FIG. 78—SOUTHERN SIERRAS POWER CO. TRANSMISSION LINE UNDER WIND STRESS
(See deflection of insulators.)



[THOMAS]
FIG. 79—PENNSYLVANIA WATER AND POWER CO. PART OF INTERIOR OF SWITCH ROOM, GENERATOR STATION, SHOWING REACTANCES



[THOMAS]

FIG. 80—PENNSYLVANIA WATER AND POWER CO.
70,000-VOLT BUS ROOM, HOLTWOOD
RESISTANCES IN NEUTRAL GROUND CONNECTION

B

CALCULATION OF LINE

CONDITIONS ON WHICH THE ORIGINAL DESIGN OF THE LINE WAS BASED

1. Size of conductors and elastic limit and modulus of elasticity assumed in the design .
2. Elastic limit and modulus by actual test.
3. Same for overhead grounded wires if used. Design value . Test value .
4. Breaking strength assumed in the design . Breaking strength by test .
5. Maximum strength pin, assumed in the design . As determined by test .
6. What maximum stress conditions were specified in the design for poles or towers, to determine their strength, e.g., was it made a condition that the line should stand, if all conductors were cut on one side of tower?
7. Maximum wind stress assumed for bare wire, pounds per square foot of projected area.
8. Accompanying air temperature assumed for question 7.
9. Maximum and minimum air temperatures assumed for determining limits of sag.
10. Maximum thickness ice assumed on conductor.
11 Accompanying air temperature assumed for question 10.
12. Accompanying wind pressure assumed for question 10, pounds per square foot of projected area.
13. Are special "strain" or "dead-end" towers used on tangents?
14. If so, where, and how often?
15. What stress conditions are these special towers designed to stand?
16. Have you any towers made flexible in the direction of the line?
17. If so, where are they placed, and how often have you dead-end towers?
18. What stresses are the flexible towers designed to stand, longitudinal and transverse?
19. If the outline of such flexible towers is not given under "Line Structure," please give sketch here.
20. Where suspension type insulators are used, what maximum angular deflection from the vertical under transverse wind strains was assumed in the design?
21. What was actually found (a) Steady wind conditions?
    (b) Swings?
22. What factors of safety were used in the design?
    a. Conductor, compare elastic limit with load .
    b. Tower structure .
    c. Overturning foundations .
    d. Overhead grounded wires .
23. Is the overhead grounded wire relied upon as part of the mechanical supporting structure in the direction of the line?

C

OPERATION

1. What is the standard method of cutting off high-tension lines, both for light and loaded lines?
2. How do you cut off a main line short circuit that holds on?
3. Do you use automatic overload circuit breakers? If so, where?
4. Are they instantaneous, inverse time limit or definite time limit?
5. What settings do you use on overload breakers and on time limit relays?
6. Do you use several relays with different time limits on different parts of a circuit and if so do the short time relays protect the others?
7. Do you use reverse energy relays? If so, what type?
8. When do they operate selectively? When non-selectively?
9. Can you clear a heavy main line short circuit without a synchronous load dropping out of step? If so, how, and under what conditions?
10. Do you operate any lines parallel at both ends? In this case can you cut out trouble on one line automatically without losing the load?
11. How do you locate line troubles?
12. Do you operate all lines from one busbar?
13. If so, is it a high-tension or low-tension busbar?
14. In case of several stations, are all connected directly to the same network?
15. How many power houses are connected to one system?
16. How many of these are water power?
17. How many are steam?
18. What are the capacities of each?
19. What is the maximum total load in system?
20. How do you regulate distribution of power between power stations?
21. How regulate voltage?
22. How do you secure constant voltage at intermediate points on a long line?
23. Where several power houses are connected to the same system, what happens when a short circuit occurs near one power house, that is, how does it affect the rest of the system?
24. Is the high-tension neutral gounded? If so, at how many points?
25. If so, is it through resistance?
26. Answer for each point of grounding.
27. If so, how much resistance?
28. How made up?
29. Have you ever operated, for even a brief period of time, with the line wire grounded?
30. If so, how long?
31. What was the effect on the rest of the system?
32. Have you a circuit breaker relay in connection with a grounded neutral to cut out automatically a single grounded line wire? If so, how arranged?
33. What is the total normal charging current of the system?
34. What is the power factor of the load at the generating station?

35. Do you use the method of operation which consists in dividing the plant into self-supporting groups and connecting the groups at some point to facilitate the carrying of peak loads and putting instantaneous overload breakers in these connections so that when trouble occurs in one section the others will be immediately cut off by these breakers and left to operate alone?
36. What are most common causes of interruption of service? If possible give the percentage of total interruptions caused by various kinds of trouble.
37. Have you any lead-covered cables operating at 20,000 volts or higher? If so, what sort? What success?
38. Are any such cables in series with overhead lines? If so, what protection is used?
39. What is the difference in voltage between the two ends of the line at full load? Specify the load and power factor at one end of the line and the length of the line.
40. How and where are the operations of the system controlled?
41. Do you have automatic voltage regulators on any of your generators?
42. If so, what kind? What results?
43. Have your oil switches ever failed to open a heavy load or short circuit?
44. If so, under what conditions? What type of switch?
45. Do you work on one line on a tower with another line alive?
46. As a matter of experience do your line insulators fail *on laboratory test* by flash-over, or by puncture?
47. As a matter of experience do your line insulators fail *in service* by flash-over, or by puncture?
48. Where suspension insulators puncture, which insulator in the string is the most likely to puncture?
49. Do the strain insulators fail more often than the vertical suspension strings?
50. Do you use synchronous apparatus to correct power factor? If so, how? With what success?
51. Do you use reactance coils for this purpose?
52. Have you had any trouble from mechanical oscillations or waves or swinging of your transmission conductor? If so, please explain.
53. At what frequency or frequencies do you operate?

NOTE. If the above questions are not suited to bring out the methods of operation or points of interest of your plant, please give such additional information as you may desire.

D

LIGHTNING AND LIGHTNING PROTECTION

1. What type and make of high-tension arresters do you use?
2. Where located in line? That is, whether indoors, outdoors, at exit from building, out on line, at what substations, etc.
3. Total number on lines
4. For what discharge voltage are they set, that is, at what margin over line voltage?
5. How often are they charged, if electrolytic arresters are used?

6. Is charging resistance used? Does this do away with high-frequency effect at time of charging?
7. How many lightning storms in average season?
8. How often do arresters discharge?
9. Do they discharge whenever one leg of the line is grounded?
10. How long will they stand a continuous discharge safely, as when there is a permanent ground on a line wire?
11. How many interruptions of service on main line per season due to lightning?
12. How many cases of high-tension station apparatus injured by lightning per season?
13. How many line insulators *punctured* by lightning per season?
14. How many line insulators *cracked* by arc over surface per season?
15. Are resistances used in ground connections of lightning arresters?
16. If so, how much?
17. Of what material and how made?

NOTE. If you have had any experience with overhead grounded guard wires on your transmission line, please summarize your evidence as to their effectiveness and give as a separate statement your views as to the desirability and effectiveness of such protection.

E

SPECIAL PROTECTION FEATURES

1. Do you use arc "suppressors?"
2. Do you use automatic grounding devices?
3. Do you use automatic line short-circuiting devices?
4. If you use any of the above, please give a brief outline of their principle of operation and your experience with them as fully as you may be willing to do so.
5. Do you use any other special forms of protective apparatus against short circuits, interruptions, or grounds, such, for example, as static cable protectors?
6. Do you use reactance coils in your circuits to prevent too heavy short-circuit currents?
7. If so, where are they located, in the system?
8. What maximum current do they permit on full voltage?
9. What could be the maximum short-circuit current of the system at the same point without these reactances coils?
10. Have you had any objectional features of such reactance coils develop?
11. Do you lower the generator field strength in case of trouble, either by hand or automatically?

F

TELEPHONE

1. How does your company telephone line run on the transmission poles or towers?
2. If not, how is it run and by what route with regard to the main line?

3. What size and material are the conductors?
4. How far spaced from transmission line, how are the telephone lines themselves spaced?
5. How transposed?
6. How is power line transposed?
7. What precautions are taken to protect users of the company phones?
8. Is the phone usable at all times during operation?
9. If not, when is it not usable?
10. What is the effect upon the telephone line of various sorts of trouble on the transmission line?

G

PRESERVATION OF WOOD

1. Do you use any treated wood?
2. If poles, how do you treat them?
3. If crossarms, how do you treat them?
4. If pins, how do you treat them?
5. How have they lasted? What length of time and under what general conditions?
6. How much does it cost to treat?
7. What disadvantages has treating?
8. For what conditions do you advocate wood, the use of wooden poles or crossarms?
9. Have you any special means of protecting pole butts from decay or fire?

H

MISCELLANEOUS

1. Have you outdoor substations?
2. Have you outdoor transformers?
3. Have you outdoor switches?
4. If either, please state essential features briefly and whether you are pleased with them.
5. Do you use "breathers" to keep moisture from tanks of outdoor type of apparatus? What sort and what success?
6. Does moisture actually penetrate your weatherproof tanks?
7. How do the high-tension terminals act in wet weather?
8. How do you protect tanks from the heat of the sun?
9. Have you tested oil from outdoor apparatus that has been over a year in service? If so, what result?
10. Do you follow the overhead crossings specifications prepared for the national standard by the Joint Committee on Overhead Line Construction of the N. E. L. A.?
11. Do you use any bimetallic or copper-clad cables?
12. If so, are they satisfactory? How used?
13. Any observations on corona?

DISCUSSION ON "ENGINEERING DATA RELATING TO HIGH-TENSION TRANSMISSION SYSTEMS" (SUB-COMMITTEE REPORT: THOMAS), DETROIT, MICH., JUNE 25, 1914.

John B. Fisken: On page 1023 it is stated for the Washington Water Power Company, "We have noted no deterioration in conductors." That, as far as I know, was true up to within the past few weeks. Since I left home I have been advised that a very serious deterioration has been noticed in some of the conductors. I have a small sample of wire here which was sent to me at Detroit, which I will give to the chairman; it shows the deterioration to which I refer. I do not know what the cause is, and I cannot account for it, unless it is a corona effect. It appears to be a very serious matter. This line has been in operation about eleven years. The first eighteen months it was operated at about 45,000 volts, and since then at 60,000 volts. The triangle is 42 inches. The insulators are carried on iron pins and wooden poles, and until about two years ago the pins were not grounded. At that time we did ground the pins and that has had some effect on the wire, possibly. I merely call your attention to this to show that we at any rate have found deterioration in the conductors.

Percy H. Thomas: There is a marked deterioration in the wire; a wasting away in spots of the metal at least 1/16 in. deep. We are greatly indebted to Mr. Fisken for bringing this point forward, and it is a matter that we should all bear closely in mind. What part of the system was this taken from, and what were the conditions surrounding the line at that point?

John B. Fisken: The climate is such that for about two months in the summer there is practically no rain. The average annual precipitation is about 22 in., and the elevation where that wire was taken down was about 2500 ft.

Percy H. Thomas: Was this deterioration noticed generally over the system, or at some particular location?

John B. Fisken: We have only gone over a few miles of the line, and it has been noticed all over that portion. This matter has only come up within the last month, so we have not had time to make a full examination of the rest of the line, which is about 100 miles long.

S. C. Lindsay: The Committee states that there were only a few companies using protective relays, and that the Puget Sound Traction, Light and Power Company does not state the result of selective action. When the data were compiled we had only two lines equipped with reverse-power relays, and we had not had a case of trouble on either line since they were installed. The question of equipping our whole system with automatic relays had been thoroughly investigated, and the equipment was being installed when these data were supplied. Since forwarding these data to the committee we have had several cases of trouble, and on the whole are getting very encouraging results from our automatic relays on networks of lines. We have three networks, 50,000-, 13,000- and 2200-volt lines. Our relay installation is not complete at this time, but within the course of a year our company will be able to contribute additional data on the question of automatic relays for protecting networks.

Percy H. Thomas: The matter of protecting telephone lines on the same towers as high-tension lines, or even in the same general neighborhood and paralleling high-tension lines, is a most important one. There are two difficulties encountered, the difficulty of talking and hearing, and the danger to the operator.

The difficulty of talking is due to electrostatic, and, to some extent, electromagnetic, induction between the high-tension line and the telephone line. It is of course the long parallelism between them that makes the situation serious, on account of the very great sensitiveness of the telephone. The telephone line is so sensitive to this disturbance that putting the telephone line a mile away from the power line will not prevent interruption of telephone service under most conditions whenever the power line is grounded or short-circuited, or by the charging of electrolytic arresters, or almost any kind of electrical disturbance.

If the telephone line is a mile away and has not protective means, talking is usually impracticable when the power line is upset from any cause. It is relatively easy, however, to protect such a telephone line so that talking is good, for example by the use of drainage coils. The drainage coil is a transformer winding connected between the two telephone wires and having its middle point grounded.

The characteristic of the voltage disturbance produced in a telephone line by the power line, which distinguishes it from the useful voltage in the telephone line producing the talk, is the fact that induction from the power line affects both telephone wires alike. If the induction is such as to raise the potential of the telephone wires they are both raised at once, and if it is such as to lower the potential they are both lowered at once. Talking through telephone wires, on the other hand, produces potentials positive on one telephone line and negative on the other. The power disturbance raises them or lowers them together. A device which will prevent a change of potential of the same sign in the two wires, but will permit potentials of opposite signs to exist in the two wires, gives the desired result of permitting talk and resisting induction. The drainage coil does just this. The induced currents which tend to flow to ground at the same time from the two telephone wires are unimpeded, since the magnetic effects in the windings will neutralize each other, and will not produce any magnetism in the core of the transformer. Therefore, the only impedance to ground they meet is due to the resistance of these windings and to whatever magnetic leakage there may be between the two halves of the winding.

Obviously, the disturbance produced in the telephone wires by the power line is of such a nature as to send a charging current into, or out of, the two telephone wires at the same time. If no charging current can flow, the induction affects the potential of the two wires. With a connection to ground, the effect of the disturbance is to produce charging current in the two wires.

It is impossible to eliminate absolutely the resistance offered by the drainage coil to the charging current to ground, but the residual 50 or 100 volts, of course, is immaterial. The one precaution to observe with this kind of protection is to make sure that there is no condition in which the power line disturbance can produce so large a charging current to the telephone wires through the drainage coils as to burn them out.

Where the exposure of a telephone line to a high-tension line is a good many miles, it is good practise to have a number of these drainage coils, so if anything happens to one, others will remain, and protection at any one point does not depend on a coil a hundred miles away.

So much for the first type of disturbance of the telephone line, and drainage coils, properly installed, are pretty nearly sufficient for protection.

The second type of disturbance is the danger to operators. The 1 to 1 transformer is certainly a very great protection, but remember this—they are generally tested at not over 25,000 volts, which is hardly sufficient, on a 100,000-volt system, to give absolute protection. It is desirable to have spark gaps and fuses as well.

The insulating transformer very materially cuts down the transmission of speech. It is not possible to speak as clearly through the insulating transformer as if the transformer were not there.

Ernest V. Pannell: In view of the very valuable data given in this report, it is scarcely fair to criticise its lack of completeness, but I think it would have been more interesting if it had been possible for the report to show how the design of the line is influenced by the conducting material used. In going through this list of transmission lines, it is notable that 40 per cent of them are using aluminum conductors to a greater or less extent. In addition we see a metal in use which I believe is copper-clad steel, and also steel-core copper and steel-core aluminum. Now if we had a thorough and exhaustive report, comparing these various materials side by side, with their advantages and disadvantages, and the various experiences in operating them, it would, I am sure, fill a very wide gap in our practical knowledge of transmission line design at the present day.

With particular reference to long spans, of course this is the incentive which has brought most of these high-tenacity materials into use, and in this connection it has frequently been said that aluminum is good for spans which do not exceed six or seven hundred feet. In view of the remarks of the Pacific Gas and Electric Company in this report, however, and of other companies operating with aluminum on their long spans, this seems no longer to hold good; and with the greater tenacity obtained in the present-day product, it would seem that aluminum is perfectly satisfactory on all spans which can be run with copper. An additional piece of information comes to my mind, and that is a transmission line recently erected in Norway, where they are putting on spans up to 2300 ft. in length, which are being made with cables of a light aluminum alloy having a tenacity of 36,000 lb. per sq. in.

Where a line has been designed for aluminum conductors as an alternative to copper, it does not seem to me that the correct principle is always followed. Almost invariably the aluminum conductors are chosen equivalent to the conductivity of the copper only. Necessarily, the aluminum will have a greater sag, and higher and more costly towers will be required. If, as an alternative, cables of larger area of cross-section were used, the tension on the lines could be increased, the sag decreased, and the towers, although they would have to be stiffer, need not be as high, and I believe the line would be more reliable throughout and at least as cheap.

If there is any information forthcoming on this matter of compound steel-copper and steel-aluminum conductors, it would be interesting to know just how the stresses are distributed in them. I take it, that where a steel-core is employed, instead of aluminum or copper, the lay of the steel is longer than that of the outer metal, so that it takes the major part of the pull.

The sample which Mr. Fisken showed to us was very interesting, and it appeared as if the trouble was due to abrasion rather than corrosion. I do not know whether anyone will bear me out in that. I will ask Mr. Fisken, in view of the fact that I believe he has some aluminum wire on his system, whether the aluminum conductors have shown similar trouble, or how they are behaving. It is a notable fact that under many atmospheric conditions which cause copper to deteriorate, aluminum has been found to operate satisfactorily.

Percy H. Thomas: What do you mean by a tenacity of 36,000 lb. per sq. in.? Is that the ultimate strength of the elastic limit?

Ernest V. Pannell: That is the ultimate strength per sq. inch.

John B. Fisken: We took down about 50 miles of aluminum wire that had been in operation for about five years and nothing of this kind was found; whether it will be in the same condition after ten years, or not, I cannot tell.

Percy H. Thomas: Possibly some of you gentleman do not happen to have noticed that we have at least two or three long transmission lines which are using a special cable with a steel center, and a number of aluminum strands wound around it, the steel being very high strength steel, and the aluminum giving conductivity and giving large diameter to keep down corona.

I wonder if there is anyone present who can give us any further information about that steel-aluminum cable.

E. E. F. Creighton: I wish to say a few words about the vacuum lightning arrester which has been under development for a number of years, to have no misunderstanding of the limitations of its use. Mr. Emerson P. Peck has taken the initiative in applying this arrester to the protection of telephone wires situated on 11,000-, 22,000- and 110,000-volt lines of the Georgia Railway and Power Company. The lightning arrester was developed specifically for signal circuits of steam railways and it was intended in these circuits to make the arrester so that it would never short-circuit. A short-circuited arrester on a signal circuit means a false signal of safety, and therefore is very dangerous. This arrester was developed with that idea in mind, to avoid the danger of short-circuiting. As a result, the arrester will stand momentarily 1000 amperes of direct current at 600 volts, while a circuit breaker opens, without having its electrodes welded together—in fact, it will do this a number of times. Opening up an arrester after tests of that kind we found the electrode very much shrunken in size, but in no case was the electrode melted in such a way as to come in contact with the outer copper tube. I am not bringing this matter up at this time to describe the arrester, but to describe the limitation, and therefore I shall pass immediately to the point in mind.

While the arrester was developed to withstand heavy current for a brief time, it was not given sufficient cooling area to discharge a small current for a long time. It frequently happens that an accidental arcing ground occurring on a system lasts for a considerable length of time before it is removed. If this arrester is so placed that discharges pass through it during this period it is liable to be overheated and damaged. Mr. Peck has apparently found no trouble from this source, and it is probably due to the fact that continuous discharges do not take place for a long time through the arrester in the position in which it was used. An arrester having plenty of cooling surface can be made for this particular service and a few of them have been put out. I think the important point is that with the arrangement that Mr. Peck has used* it seems unnecessary to take the precaution of using a larger lightning arrester and a more expensive one in order to keep it cool.

In the matter of the damage done to the wire which Mr. Fisken showed, we have had in certain types of apparatus which we have built in the laboratory something quite similar that makes us think it is the same thing. An electrostatic relay in which an insulator was used to furnish the electrostatic pull produced just such corona, which formed nitrous oxide, and with the natural moisture in the air, formed nitric acid. This corona discharge, which was a little heavier than the blue discharge which gives ozone, was confined in a glass box. The nitrous oxide continued to increase in density, and as a result every one of the metal parts inside, except the aluminum, was very badly corroded. It would seem that this is the same thing that Mr. Fisken found, in that the wire is eaten out directly above the insulator where it lay on top of the porcelain, in the location where the corona would be the strongest. Taking into account the high altitude and the fact that the insulators were made many years ago, it would lead one to believe that the static charging current in that insulator might be sufficient to get the corona above the value which causes ozone, into that region of discharge where nitrous oxide is formed. One can easily determine visually the intensity of corona discharge which forms nitrous oxide. It is marked by the appearance of definite little threads or bright streamers in the otherwise uniform blue brush discharge.

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*Pages 1042-1046, this volume.

Percy H. Thomas: What Professor Creighton says certainly sounds very reasonable, and I want to ask Mr. Fisken if any of the insulators in this neighborhood are on wooden pins.

John B. Fisken: All iron pins.

Percy H. Thomas: Have you examined the tops of any of the pins—do they show any sign of deterioration?

John B. Fisken: No.

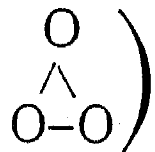
Percy H. Thomas: I should say the iron would be attacked by nitrous oxide if it existed.

John B. Fisken: We have taken off a number of pins and never noticed anything of that kind.

Percy H. Thomas: Are they set in cement?

John B. Fisken: No, in lead.

Percy H. Thomas: The digestion of tops of wooden pins suggests this same sort of action.

F. W. Peek, Jr.: The explanation of the brush discharge as the cause of the deterioration of the line conductor, which Mr. Fisken has shown, is undoubtedly the correct one. This occurs at or near the insulator. Where the wire is tied to the insulator there is the metal conductor, a thin film of air, a thickness of porcelain, and the pin. There is thus a condenser with the line conductor as one plate, air and porcelain in series as the dielectric, and the metal pin as the other plate. The voltage across this condenser is equal to line voltage divided by $\sqrt{3}$. The same dielectric flux passes through the porcelain to the air. The permittivity of air is 1 and of porcelain is 5. The porcelain "conducts" the dielectric flux five times as well as air. The voltage gradient in the the air film is thus five times what it is in certain parts of the porcelain. This air film breaks down as a brush. Air consists of a mechanical mixture of oxygen and nitrogen. The oxygen is O_2 $(O=O)$ and is inactive. In the brush it splits up as O. Recombination takes place as O_2 and O_3 (ozone, ). Both O and O_3 are chemically active and oxidize the conductors. At high gradients on the air, nitrogen also combines with the oxygen and in the presence of moisture forms nitric acid. This also attacks the conductor. Each insulator is a small ozone and nitric acid generator. It can be prevented by a properly placed corona shield.

Aluminum is affected to a much less extent by the above cause. Either aluminum or copper may, however, deteriorate very rapidly due to desulphurizing, and other mining processes.

Percy H. Thomas: I want to call attention to the fact that it is not excessive line potential, primarily, that breaks down the small air gap between the insulator and the conductor, it is the *fall of potential* across the air gap itself. With a small enough air gap, a low potential will produce this breakdown. Mr. Peek has spoken of a similar action in the windings at the end of the coils of the armature of a 200- or 300-volt generator, where a concentration of potential may under some circumstances be sufficient to produce this acetic or nitric acid formation, and deteriorate the insulation. The same thing occurs in rubber-covered underground cables where there is a great concentration of potential, and when the ends of the rubber covering are exposed to the air there is oftentimes a hardening or deterioration of the rubber due to oxidation from the formation of ozone. Those of you who use suspension insulators may feel secure in this matter with the idea that the insulators are connected to the conductor by a metal clamp, and no difference of potential can occur to form nitric acid on the conductor in the clamp.

R. Fleming: Regarding the action of nitric acid under atmospheric conditions, I do not remember having seen it proved very conclusively just what action takes place. It seems to me we have here an opportunity to get at least tentative proof as to what action takes place. It is surely chemical. On examining the sample of wire you will find there is plenty of deposit which would enable a chemist to analyze and determine its chemical nature. It is probably sulphate, it may be nitrate, or it may be carbonate of copper. The electric discharge alone would probably not disintegrate wire in the manner here shown.

H. H. Norton: I would suggest that a number of samples be collected and submitted for analysis to some chemist capable of performing such an analysis. It would require considerable work to do it. I ask Mr. Fisken if there are any smelters in the vicinity. Smelter fumes are likely to produce sulphates.

M. von Recklinghausen: I have examined this piece of wire, and to me as a chemist it looks strange that it is attacked deeply on two points. These are probably the points where the tie wire has touched this wire. There may be two explanations here—one is mechanical, but I do not think that is likely. The other may be electrolysis. The tie wire is not of the same metal, although both are supposed to be pure copper. Both are not pure copper. They are different in composition, and it is possible that there is some electrolytic action going on between the two and the humidity from the atmosphere. I offer that also combines with the oxygen and in the presence of moisture forms nitric acid. This also attacks the conductor. Each insulator is a small ozone and nitric acid generator. It can be prevented by a properly placed corona shield.

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M. von Recklinghausen: I have examined this piece of wire, and to me as a chemist it looks strange that it is attacked deeply on two points. These are probably the points where the tie wire has touched this wire. There may be two explanations here—one is mechanical, but I do not think that is likely. The other may be electrolysis. The tie wire is not of the same metal, although both are supposed to be pure copper. Both are not pure copper. They are different in composition, and it is possible that there is some electrolytic action going on between the two and the humidity from the atmosphere. I offer that tary way such a system might be represented by the diagram in Fig. 1, herewith, which represents a generating station connected to a substation by two transmission lines.

The normal condition of operation would be to have all of the generators in parallel on the bus *A* and all of the feeders in parallel on the bus *D*. The high-tension buses *B* and *C* would normally be opened by *S* and *T*. Switches *E* and *G* would be equipped with inverse time limit relays. Switches *K*, *P*, *R* and *M* would be non-automatic, and switches *F* and *L* would be equipped with reverse power relays. In case of trouble, then, on one line, say at *X*, the switch *F* would be opened by the reverse power relay. Switch *E* would be opened by the overload relay. The load would be automatically thrown over to the other line without interruption of service. This means that for a short time the second line and its transformers would possibly be overloaded, but in the worst case such an overload would not exceed 100 per cent and the apparatus should be capable of carrying such an overload for a period of time sufficient to open switches *K* and *M* and close switches *S* and *T*, after which transformer banks *H* and *I* can again be put into service in parallel with *V* and *W* on the second line.

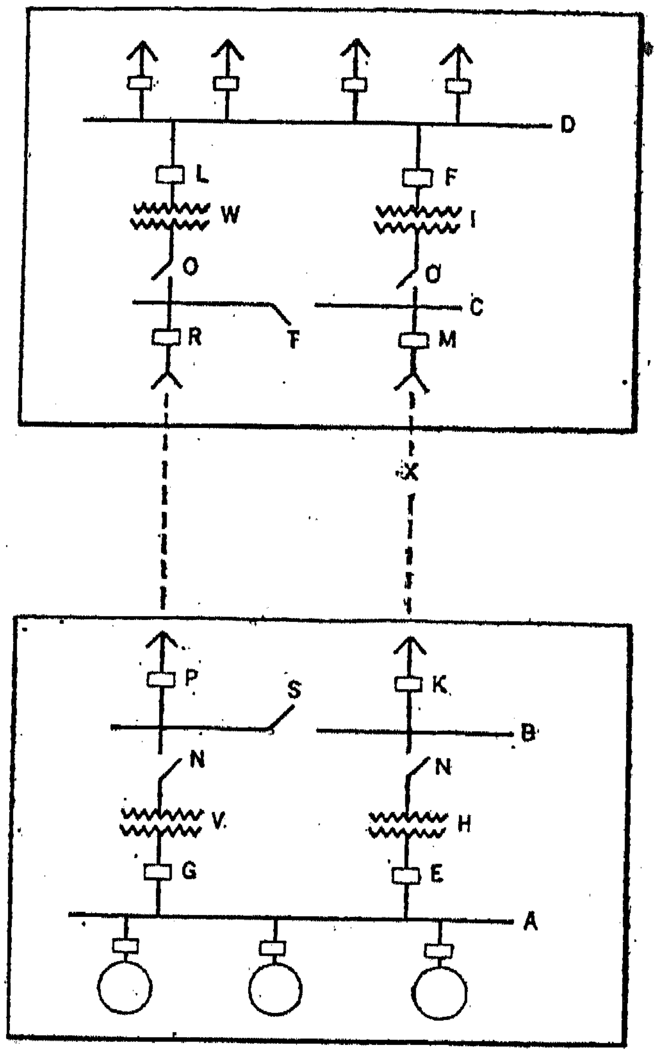

FIG. 1

The scheme of operation would be exactly the same if each of the four transformer banks shown were replaced by two or more banks, so long as they were paralleled on one high-tension line, under which conditions, in order to clear the line, it would be necessary to cut off all of the low-tension transformer switches involved. Usually it is not practicable to carry much over 20,000 kw. on a single transmission line, and a single bank of transformers can readily be used with a line of such capacity, that is, each single-phase transformer would be rated at say 6666 kw. Such a size would be economical for high-voltage design and the entire layout would be cheaper, as regards both transformers and switching equipment, than if a greater number of transformer banks were used.

This system permits, under ordinary conditions, all of the automatic switching to be done on the low-tension side, which in itself is an advantage. Some tests were made about two years ago on a large 44,000-volt system by putting spark gaps across individual coils of the high-potential winding of a transformer and setting up disturbances on the high-tension line. The voltages across the coils, indicated by the spark gaps, varied from something like three to four times normal in case of an arcing ground to about twenty times normal for operation of a high-tension switch. Such results merit careful consideration. Further, with the transformers grouped with relation to each line, instead of being paralleled on the high-tension bus, the effective reactance in circuit when a short circuit occurs in the high-tension line is so much higher that the rush of current is materially lessened, thus decreasing the danger of damage to line insulators by high-power arcs and of burning off line conductors. I believe that entirely aside from any question of the danger of high-tension switching, the advantages of such a system of connections merit its use simply from the standpoint of decreased first cost of transformers and switching equipment, and the reduction in destructive effects of line disturbances, due to the increased effective reactance.

In the past, some objection has been made to reverse energy relays, as it was claimed that under the potential drop due to short circuit they would fail to operate properly. This difficulty has been practically done away with in most of the reverse energy relays now on the market, and further, under the conditions which usually obtain, they will not operate on overloads. Only recently, in putting into service a 120,000-volt system, about 150 miles long, where the principles indicated above were carried out strictly, a short circuit was made on the high-tension side of one of the substation transformers. The reverse energy relay acted promptly, notwithstanding the drop produced by the short circuit. Several other occurrences took place causing line disturbances, such as a lightning stroke on the line close to the generating station, a short circuit produced by wire falling across transmission line, etc., but in each case the relays operated properly so as to cut out only the line in trouble, without interrupting service. The diagram, Fig. 1, shows only two simple stations. The same principles, however, can be applied to any number of stations and substations tied together in a system, provided there are two transmission circuits.

E. A. Lof: There is one point of particular interest in this report, and this is the section on pages 1029 and 1030 dealing with the operation of a system with one of the phase wires grounded. It is notable here that for systems of very high voltage the effect of such an operation has been rather severe. One company, for example, states that it has had numerous punctures of insulators and breakdowns of bushings, while another company states that the effects have been too severe to operate its system with one wire grounded.

This brings out an important point. For a Y-connected system with the neutral grounded, the grounding of one phase wire will short-circuit this particular phase and the circuit breakers will trip, thus entirely cutting out the line. For a non-grounded, delta-connected system, however, the grounding of one phase will have the effect of increasing the capacity of the line. Under normal operation this capacity is in proportion of the voltage to the neutral, but when one line becomes grounded this voltage is increased to the full line potential, and the charging current will be proportionately increased. This in turn raises the voltage at no-load, which will be about 70 per cent higher than it would be when under normal operation. Actual experience has proved that this is the case and it probably will be one of the most important factors which will decide against delta connection for systems of very high voltage.

Selby Haar (by letter): The report which is now laid before the Institute is a thorough piece of work, and one which fully entitles the committee to the special thanks of the members. It is regrettable, however, that approximately complete replies were obtained from less than one-fourth of the companies addressed.

The writer, having recently made a somewhat similar investigation (covering transmission systems all over the world, however), would like to call attention to certain practises brought out in the report by citing other solutions of the same problems. (The numbering of the following items refers to the list of questions given in the Appendix to the committee report).

A-2. The tower is seldom used abroad, metal poles being selected for high voltages, and wood or concrete for lower voltages.

B-1 to 15. The following data apply to a 70,000 -volt Swiss line recently built.

1. 19-strand cables 0.394 in. diameter, breaking strength 57,000 lb. per sq. in., $E = 17{,}700{,}000$ lb. per sq. in. (working stress 8500 lb. per sq. in.).
3. 7-strand cables 0.315 in. diameter, breaking strength 113,000 lb. per sq. in., $E = 31{,}500{,}000$ lb. per sq. in.
6. Wind pressure only, for ordinary poles.
7. 14.3 lb. per sq. ft.
8. −25 deg. cent.
9. + 40 deg. cent.; − 25 deg. cent.
10. Snow (not ice) 0.394 in. thick, weighing 10 lb. per cu. ft.
11. − 25 deg. cent.
12. 14.3 lb. per sq. ft.
13. Yes.
14. Every $\frac{2}{3}$ to 1 mi.
15. All wires on one side broken, and wind pressure of 20.4 lb. per sq. ft. adding directly to conductor pull.

B-23. This is not infrequently claimed.

C-24. In Europe, the high-tension neutral is usually not grounded, but the generator neutral is.

C-38. The transmission line of the Moutiers-Lyons direct-current system in France, the operating voltage of which has reached about 80,000 volts, includes about 2.5 miles of cable (out of 112).

D-1. Foreign operating companies use the same types of lightning arresters for all high tensions, namely, horn gaps with series resistance, reactance coils, and liquid static dischargers. Condensers are being tried in several places. There is also to be noted an attempt to proportion the whole transmission and switching system to minimize as far as possible the generation of excess voltages.

E-1. The opinion of several experienced American engineers is that an effective arc suppressor and a plain horn gap, set rather high, give protection which is "hard to beat."

For the benefit of members who have to examine certain features of transmission plants in great detail, a list of references, mostly to periodical literature, collected by the writer in his investigation (*Electrical World*, April 25, 1914, p. 925) is appended. In this list are descriptions, etc., of over fifty plants designed for 70,000 volts or above.

HIGH-VOLTAGE POWER TRANSMISSION SYSTEMS

Pacific Light and Power Co., 150,000 volts.
  Elec. Jl. 1913, p. 768.
  Elec. Rev. & West. Elecn. 3-1913, p. 583.
  Elec. Wld., 6-1912, p. 1200, 1342; 11-1913, p. 1108; 1-1914, p. 337, 385.
  Elek. Zeit., 10-1913, p. 1242.
  Eng. News, 11-1913, p. 843.
  Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
Au Sable Electric Co., 140,000 volts.
  Elec. Wld., 4-1912, p. 795, 843; 6-1912, p. 1195.
  Elek. Zeit., 10-1913, p. 1242.
  Eng. Mag., 4-1913, p. 53.
  Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
  Lundquist, "Transmission Line Construction," p. 46.
Southern Sierras Power Co., 140,000 volts.
  El. Rev. & West. Elecn., 10-1912, p. 814.
  Elec. Wld., 8-1912, p. 298; 8-1913, p. 234.
  Elek. Zeit., 10-1913, p. 1242.
  Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
  Jl. Elec., Pr., Gas 7-1913, p. 1, 33.
Utah Power & Light Co., 130,000 volts.
  Elec. Wld., 7-1913, p. 106.
  G. E. Rev., 1913, p. 359.
Pacific Gas & Electric Co., 125,000 volts.
  Elec. Wld., 11-1913, p. 1055.
  Eng. Rec., 11-1913, p. 573.
West Penn. Traction & Water Power Co., 125,000 volts.
  Elec. Rev., & West. Elecn. 11-1912, p. 990; 4-1913, p. 726.
  Elec. Wld., 6-1912, p. 1280.
  Iron Age, 11-1912, p. 1296.
Tennessee Power Co., 120,000 volts.
  Elec. Rev. & West. Elecn., 2-1913, p. 267.
  Elec. Wld., 4-1912, p. 820; 3-1913, p. 644,696; 5-1913, p. 1111; 10-1913, p. 868.
  Power, 3-1914, p. 360.

Connecticut River Transmission Co., 120,000 volts.
  Elec. Wld., 10-1913, p. 685; 3-1914, p. 565.
Inawashiro Hydroelectric Power Co., 115,000 volts.
  Elec. Wld., 3-1912, p. 524; 5-1913, p. 1058.
  Engg. London, 10-1913, p. 35.
  Z. V. d. I., 4-1912, p. 569.
Au Sable Electric Co., 110,000 volts.
  Elec. Wld., 11-1906, p. 841; 11-1907, p. 850; 2-1909, p. 354; 9-1909, p. 664; 6-1912, p. 1195.
  Elek. Zeit., 10-1913, p. 1242.
  Eng. Mag., 4-1913, p. 53.
  Eng. Rec., 10-1907, p. 418, 462.
  G. E. Rev., 1909, p. 86.
Hydroelectric Power Commission of Ontario, 110,000 volts.
  Elec. Wld., 1-1912, p. 33, 96, 137; 6-1912, p. 1195.
  Elecn., London, 3-1912, p. 912.
  Elek. Kr. & B., 1909, p. 337; 1910, p. 526, 727.
  Elek. Zeit., 10-1913, p. 1242.
  Eng. Mag., 4-1913, p. 53.
  G. E. Rev., 1912, p. 336; 1913, p. 352.
  Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
  TRANS., A. I. E. E., 24-1905, p. 807.
  Lundquist, " Transmission Line Construction," p. 45.
Lauchhammer, A. G., 110,000 volts.
  Elec. Wld., 10-1911, p. 1057; 6-1912, p. 1195.
  Elek. Zeit., 1911, several places; 10-1913, p. 1242.
  Lundquist, " Transmission Line Construction," p. 96, 97.
Georgia Railway & Power Co., 110,000 volts.
  Elec. Rev. & West. Elecn., 2-1913, p. 267.
  Elec. Wld., 5-1911, p. 1127; 6-1912, p. 1195; 12-1913, p. 1257, 1309.
  Elek. Zeit., 10-1913, p. 1242.
  Eng. Mag., 4-1913, p. 53.
  Eng. News, 1-1914, p. 240.
  G. E. Rev., 1912, p. 336; 1913, p. 352; 1914, p. 608.
  Alabama Power Co., 110,000 volts.
  Elec. Wld., 3-1912, p. 610; 1-1913, p. 68; 6-1913, p. 1278; 9-1913, p.527
  G. E. Rev., 1913, p. 386.
Mississippi River Power Co., 110,000 volts.
  Elec. Wld., 4-1913, p. 715; 5-1913, p. 1157.
  Elek. Zeit., 10-1913, p. 1231, 1242.
  Eng. Mag., 4-1913, p. 53.
  G. E. Rev., 1912, p. 336; 1913, p. 352; 1914, p. 85, 375.
  Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
Lehigh Navigation Electric Co., 110,000 volts.
  Elec. Wld., 4-1913, p. 902; 5-1914, p. 1035, 1093.
Cedar Rapids Manufacturing & Power Co., 110,000 volts.
  Elec. Wld., 4-1913, p. 902; 7-1913, p. 105; 8 -1913. p. 319.
  Eng. Rec., 10-1913, p. 461.
  G. E. Rev., 1913, p. 336.
Mexican Northern Power Co., 110,000 volts.
  Elec. Wld., 5-1913, p. 1190; 7-1913, p. 155.

G. E. Rev., 1912, p. 336.
Ebro Irrigation & Power Co., Ltd., 110,000 volts.
Elec. Wld., 1-1913, p. 212.
Chile Exploration Co., 110,000 volts.
Elec. Wld., 5-1913, p. 1191.
Eng. & Min. Jl., 1-1914, p. 63.
Sierra & San Francisco Power Co., 104,000 volts.
Elec. Wld., 6-1912, p. 1193; 9-1908, p. 667; 10-1908, p. 946.
Elek, Kr. & B., 1910, p. 160.
Eng. Mag., 4-1913, p. 53.
Eng. News, 5-1909, p. 516.
G. E. Rev., 1912, p. 336; 1913, p. 352.
Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
Lundquist, " Transmission Line Construction," p. 45.
Great Falls Power Co., 102,000 volts.
Bull. A. I. M. E., 8-1913, p. 1907.
Elec. Wld., 6-1912, p. 1195.
Elek. Zeit., 10-1913, p. 1242.
Eng. Mag., 4-1913, p. 53.
G. E. Rev., 1911, p. 149, 207; 1912, p. 336; 1913, p. 352.
Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
TRANS. A. I. E. E., 1911, p. 2002.
Yadkin River Power Co., 100,000 volts.
Elec. Wld., 3-1911, p. 748; 4-1911, p. 799; 5-1911, p. 1128; 8-1911, p. 261, 4-1912, p. 774.
Elek. Zeit., 10-1913, p. 1242.
Eng. Mag., 4-1913, p. 53.
G. E. Rev., 1912, p. 336.
Colorado Power Co., 100,000 volts.
Elec. Wld., 1-1910, p. 217, 6-1910, p. 1649; 6-1912, p. 1195, 1205.
Elek. Zeit., 10-1913, p. 1242.
Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
Lundquist, " Transmission Line Construction," p. 47.
Taylor, " Transformer Practise," p. 270.
Great Western Power Co., 100,000 volts.
Elec. Rev. & West. Elecn, 2-1913, p. 267.
Elec. Wld., 8-1909, p. 471; 9-1909, p. 657, 712; 6-1912, p. 1193, 1195; 6-1913, p. 1277.
Elek. Kr. & B., 1910, p. 160.
Elek. Zeit., 10-1913, p. 1242.
Eng. Mag., 3-1910, p. 851, (vol. 38).
Eng. News, 5-1909, p. 516.
G. E. Rev., 1911, p. 6, 1912, p. 336; 1913, p. 352.
Glas. An., 6, 7, 8-1913, p. 224, 5, 24, 51.
TRANS. A. I. E. E., 1911, p. 1994.
Taylor, " Transformer Practise," p. 270.
Southern Power Co., 100,000 volts.
Elec. Jl., 1911, p. 329.
Elec. Wld., 12-1907, p. 1241; 3-1910, p. 741; 7-1911, p. 17; 6-1912, p. 1195.

Elek. Kr. & B., 1911, p. 175.
Elek. Zeit., 10-1913, p. 1242.
G. E. Rev., 1909, p. 551; 1910, p. 24; 1912, p. 336; 1913, p. 352.
Eng. Mag. 4-1913, p. 53.
TRANS. A. I. E. E., 1908, p. 819; 1911, p. 1998.
Lundquist, " Transmission Line Construction," p. 48.

Shawinigan Water & Power Co., 100,000 volts.
Elec. Wld., 5-1912, p. 953, 1015; 6-1912, p. 1195.
Elek. Zeit., 10-1913, p. 1242.
G. E. Rev., 1913, p. 352.

Los Angeles Aqueduct, 100,000 volts.
Elec. Wld., 1-1912, p. 30; 5-1913, p. 955.
Eng. Rec., 8-1913, p. 476.

Tata Hydroelectric Co., 100,000 volts.
Elec. Wld., 6-1913, p. 1332; 11-1913, p. 950.
Engr., London, 4-1911, p. 402.
Engg., London, 10-1913, p. 547, 578.
Eng. Rec., 11-1913, p.

Societa Italiana di Elettrochimica, 88,000 volts.
D'Elettricita, 12-1913, p. 72.
Elec. Rev., Lond., 11-1910, p. 832; 12-1910, p. 913.
Elec. Wld., 9-1910, p. 741.
Elecn., Lond., 4-1910, p. 67.
La Rev. Elec., 8-1910, p. 119.

Appalachian Power Co., 88,000 volts.
Elec. Wld., 11-1912, p. 1141.
Eng. Mag., 4-1913, p. 53.
G. E. Rev., 1912, p. 336; 1913, p. 352.
Taylor, " Transformer Practise," p. 270.

Rio Janeiro Tramway Light & Power Co., Ltd., 88,000 volts.
Elec. Wld., 5-1909, p. 1153; 8-1909, p. 367; 4-1913, p. 897.
Elecn., Lond., 8-1911, p. 694.
Elek. Kr. & B., 1910, p. 584; 1911, p. 175.

Tasmania Hydroelectric & Metal Co., 88,000 volts.
Australian Mining Standard, 3-1911, p. 296.
Elec. Wld., 4-1912, p. 820.
Engg., Lond., 11-1910, p. 709.
Garcke, " Manual of Electrical Undertakings," vol. 17, p. 1437.

Mexican Light & Power Co., 85,000 volts.
G. E. Rev., 1912, p. 336.
Trans. A. S. C. E., vol. 58, 1907, p. 37.
Taylor, " Transformer Practise," p. 270.

Toronto Power Co., 85,000 volts.
Elec. Rev. & West. Elecn., 7-1906, p. 138.
Eng. Mag., 3-1910, p. 855.
Trans. A. S. C. E., vol. 65, 1909, p. 181.
Lundquist " Transmission Line Construction," p. 43.
Taylor, " Transformer Practise," p. 270.

Victoria Falls & Transvaal Power Co., 84,000 volts.
Jl. (British) I. E. E., 6-1913, p. 2.

Trans. So. Afr. I. E. E., 1913, p. 170.
Klingenberg, " Baugrosser Elektrizitaetswerke," p. 177.
Energia Electrica de Cataluna, 80,000 volts.
Engr., Lond., 10-1912, p. 384.
Z. V. d. I., 11-1912, p. 1791.
Swedish State Railways, 80,000 volts single-phase.
Elek. Kr. & B., 11-1913, p. 658; 3-1914, p. 161.
Katsuragawa Denryoku Kabushiki Kaisha, 77,000 volts.
G. E. Rev., 1912, p. 336.
Southern California Edison Co., 75,000 volts.
Elec. Wld., 8-1907, p. 277, 317, 359, 401; 10-1909, p. 1039; 6-1912, p. 1190, 1195.
Au Sable Electric Co., 72,000 volts.
Elec. Wld., 11-1906, p. 841, 9-1907, p. 528.
Elek. Zeit., 1909, p. 478.
Societa Generale Elettrica dell'Adamello, 72,000 volts.
Elecn., Lond., 7-1912, p. 608, 649.
Engr., Lond., 9-1912, p. 293, 319, 349, 373, 401.
Eng. News., 12-1911, p. 764.
Montana Company, 70,000 volts.
Bull. A. I. M. E., 8-1913, p. 1907.
Elec. Wld., 7-1901, p. 53; 5-1908, p. 1088; 8-1910, p. 432.
Elek. Kr. & B., 1911, p. 175.
Eng. News, 10-1910, p. 430.
Trans. A. S. C. E., vol. 50, 1903, p. 212.
Taylor, " Transformer Practise," p. 270.
Hidroelectrica Espanola Molinar, 70,000 volts.
Elek. Zeit., 1911, p. 535, 561, 586, 766.
Pennsylvania Water & Power Co., 70,000 volts
Elec. Wld., 10-1910, p. 929; 5-1911, p. 1125; 8-1912, p. 395; 11-1913, p. 924; 2-1914, p. 314.
Eng. Mag., 3-1910, p. 855; 4-1913, p. 53.
G. E. Rev., 1912, p. 36, 336, 658; 1913, p. 352, 389, 390.
Swedish State Railways, 70,000 volts.
Die Turbine, 3-1911, p. 202.
Elek. Kr. & B., 1912, p. 126, 763.
Engr., Lond., 5-1912, p. 587.
Ming. & Eng. Wld., 5-1912, p. 1085.
City of Winnipeg, 66,000 to 72,000 volts.
Elec. Rev. & West. Elecn., 12-1911, p. 1119.
Elecn., Lond., 3-1912, p. 831, 870.
Engg., Lond., 7-1912, p. 107, 143.

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PROVISIONAL SPECIFICATION FOR INSULATOR TESTING*

COVERING INSPECTION AND TESTS OF HIGH-TENSION LINE INSULATORS OF PORCELAIN, FOR OVER 25,000 VOLTS

The present provisional specification was approved and recommended by the Power Transmission Committee of the American Institute of Electrical Engineers, February, 1915.

SPECIFICATION

Introductory:

This specification covers certain methods of test and inspection which have been found well suited for testing high-tension line insulators for use under the ordinary conditions of power transmission work. It is expected to serve as a skeleton or model specification and may be supplemented by such additional provisions as may be appropriate for any particular case.

Certain portions of the specification are added as a guide where designs are to be offered by several bidders for competitive tests. In such a case bidders will understand from the specification all the requirements they must ultimately meet if their bids be accepted.

GENERAL SPECIFICATION COVERING ALL TYPES OF INSULATORS

1. a. This specification is intended to cover the checking of the design and the testing and the inspection of the factory output, of..............................porcelain insulators, cat. No.................. of.................................Company; to be manufactured for the ....Company.

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*This specification was revised in February 1915 and is printed here in its amended form.

b. The operating voltage is............................and the frequency is.............................

c. Definitions: By "insulator" is meant the complete insulator or group of insulating members including all the parts necessary to support the conductor from the crossarm or on the pin as the case may be.

By "unit" or "unit insulator" is meant a suspension insulator element complete, having a metal cap and pin.

By "shell" is meant a single porcelain piece without cement or cap or pin.

2. *Drawings:*

A dimensioned drawing shall be furnished showing the complete insulator and metal parts, or, if the insulators are built up or composed of a string of units, showing the details of a unit and all the clearances between units and metal parts.

3. *Inspection:*

The maker will give to the purchaser or his representative such access to his works at all times during working hours as is reasonable and necessary to determine the suitability of material to be supplied, and shall furnish all necessary apparatus, labor, and other facilities for making the tests herein called for without cost to the purchaser. All good insulator units destroyed in the tests here called for are to be paid for by the purchaser at the contract price.

All insulators are subject to final inspection, test and acceptance at maker's factory.

Neither the inspection nor waiving of inspection nor the purchaser's acceptance will relieve the maker from obligation to furnish material in accordance with this specification.

4. *Design:*

All insulators shall be designed as far as may be practicable to fail by flash-over and not by puncture under excess voltage tests, especially under impact tests.

Insulators shall be of robust construction and design so as not to be easily injured in handling.

Explanatory Note:

The ultimate criterion of the merit of an insulator is its performance in service and the best available measure thereof is its behavior under definite tests. However, as no practicable tests actually reproduce service conditions, for example in the matter of high-frequency voltage or deposits of dust, criticism on theoretical grounds is valuable, and, other things being equal, preference should be given to the insulators most closely conforming to theoretically best designs.

Altitude:

Careful attention in specifying flash-over voltages should be given to the fact that for varying altitudes the breakdown strength of air varies approximately though not exactly as the barometric pressure.

METAL PARTS

5. *Corrosion:*

All metal parts shall be of non-corrodible material or shall be galvanized or sherardized in accordance with the specifications for galvanizing prescribed by the joint committee of the National Electric Light Association in its Specification for Overhead Crossings of Power Lines Above Telephone and Other Low-Voltage Lines. Surfaces shall be free from roughness or projecting points; bearing surfaces shall be smooth enough not to injure cables.

6. *Factor of Safety:*

Metal parts shall have a factor of safety of at least three over the maximum stress that they receive in service, except that with pins for pin type insulators the factor may be reduced to two where a higher factor is impracticable. The maximum service strain is here agreed upon as————lb.

PORCELAIN

7. *Quality:*

All porcelain shall be dense and homogeneous as is best adapted to high-tension insulator requirements, free from injurious cracks, blisters and flaws or other defects that would render it unfit for use in insulators. The burning of all porcelain sections shall be done so as to insure even vitrification but shall not render the porcelain unduly brittle. The surface shall be smooth and uniform and the body of the porcelain shall be moisture-proof.

8. *Glazing:*

The glazing shall be of....................color and of a reasonably uniform shade, smooth, hard and continuous over all surfaces except those to be in contact with the cement. It shall be unaffected by weather, ozone, nitric acid, nitric oxides, alkali dust, or sudden changes in temperature over the atmosphere range.

9. *Absorption: Explanatory note.*

While imperviousness of the porcelain to moisture is of supreme importance, no satisfactory test of this quality is known.

CEMENT

10. *Assembling:*

All cemented joints between insulator parts shall be carefully made, using for this purpose the best grade of neat Portland cement, thoroughly mixed, and plentifully supplied with moisture during setting. The assembly shall be so done that no hollows or voids will be left between the cemented surfaces. All superfluous cement must be cleaned off of the insulator before crating.

ELECTRICAL TESTING

Note. Sections 11 to 15 inclusive are particularly applicable to competitive tests and to tests the results of which are to be compared to similar tests made with other testing apparatus. In cases where merely a comparative study of different designs of the same make is to be made, all tests being carried out on the same testing apparatus, it is usually satisfactory to use the standard test apparatus of a first-class maker.

It should be definitely stated in the contract whether sections 11–15, inclusive, are to be adhered to or not.

11. *Wave Form:*

The wave form of the generator shall be a true sine curve within the limits specified for generators by the Standardization Rules of the American Institute of Electrical Engineers and may be checked by the methods therein prescribed.

12. *Control of Voltage:*

The voltage shall be controlled in such a way as not to distort the wave form.

One satisfactory method of control is the use of a regulator consisting of a shunt resistance connected directly across the low-voltage side of the transformer, and a series resistance in the supply. The shunt resistance must always bypass at least five (5) times the exciting current of the transformer. The principal control is effected by the series resistance. This method is often spoken of as the potentiometer method.

13. *Measurement of Voltage:*

The method of measuring the voltage on the test circuit shall be that method recommended by the American Institute of Electrical Engineers, covering such cases.

14. *Kilovolt-Ampere Capacity of Testing Apparatus:*

The kilovolt-ampere capacity of the testing apparatus, including any series resistance used, is important, for the leading current taken by the insulators tends to alter the voltage of the test apparatus. The maximum current taken from the test apparatus shall not be so great as to distort the voltage wave more than permitted for generator electromotive force waves by the A.I.E.E. Standardization Rules.

15. *Surrounding Conditions During Tests:*

In *design checking* tests of insulators having an operating voltage not exceeding 75,000 volts, no object other than leads and supports should approach nearer than 6 ft. (1.8 m.) to the insulator. For insulators having a higher operating voltage, the conditions for the " design test " of complete insulators should be made as nearly as practicable the same as the conditions of actual service as regards the grounding of one side of the insulator and the arrangement and distance of grounded objects in the neighborhood. A conductor of 6 ft. (1.8 m.) or more in length, extending equally on both sides of the clamp, should be used to represent the transmission wire.

NOTE—In these tests the walls of the room will ordinarily introduce a very serious departure from the conditions of outdoor service. Open-air tests where feasible are preferable from this point of view.

Routine tests, not being on complete insulators or insulator strings, do not require these precautions.

16. *Frequency:*

Tests should be made at the frequency at which the insulator is to be used. Where special agreement is made tests may be made at 60 cycles on insulators intended for use on higher and lower frequencies. No error of a serious magnitude will be expected within the range of 25 to 133 cycles.

17. *What Constitutes a Breakdown or a Flash-over:*

An insulator is said to " fail " or " break down " under a voltage test whenever a puncture occurs in any part of the insulator. It is said to flash over when a discharge of any sort passes all the way from one terminal to the other, since such a discharge would be followed by an arc on a power line.

Local breakdown, either corona or local sparks, while an important symptom, indicating severe local stress, does not constitute a flash-over. The weight to be given to such local breakdown, however, is a matter of judgment.

18. *Rain Tests:*

Water should be sprayed on the insulator at a uniform rate averaging 1 in. (2.5 cm.) depth in 5 minutes, and should be reasonably uniformly distributed over the whole insulator. The rate of precipitation shall be measured by collection of water in a pan at the location of the insulator, the insulator being removed. A fairly satisfactory spray in the form of a fine mist can be obtained by some forms of spray nozzles where pressure is available.

The spray shall strike the insulator at an angle of approximately 45 deg. with the vertical.

The water used shall have a high specific resistance, not less than 5000 ohm-inches (12,700 ohm-centimeters). Pure water may often be obtained from condensed steam or melted ice, preferably artificial ice, or rain. Municipal water supplies are often so impure as to seriously impair the performance of the insulator on the wet flash-over.

When insulators are to be used in localities subjected to salt spray or alkali or acid mists, or to conditions producing dew deposits, special tests may be agreed upon.

19. *Puncture Under Oil:*

Tests on a certain percentage of insulator units, ordinarily not exceeding $\frac{1}{4}$ of one per cent, should be made to determine the ability of the insulator to resist puncture and to measure the uniformity of the product. This test is best made by submerging the insulator in oil.

For this test each suspension insulator unit should be completely assembled with its standard metal parts.

With pin type insulators there should be attached to the head of the insulator wires representing the tie and line wires, and a metal pin should be placed in proper manner in the pin hole.

The test voltage should then be applied to the metal parts in each case. The puncture value obtained under these conditions should not be less than 150 per cent of the dry flash-over voltage and should, where possible, be much higher. In the case of suspension units a factor approaching 200 per cent has sometimes been obtained.

The puncture voltage that must be met in the actual tests (§25) should be here specified for each contract, viz., ...volts.

In making the test, apply to the insulator a voltage 30 to 40 per cent below the dry flash-over value and then raise the voltage gradually or by steps, until puncture occurs, at a rate of about 10,000 volts per second. The puncture value of porcelain is very sensitive to the length of time voltage near the maximum is applied; the puncture voltage may be lowered as much as 20 per cent by long-continued application of the test voltage.

20. *Series Spark Gap:*

In routine testing, it is well to have a short air gap between each insulator under test and the testing line, that the character of the charging current may be judged by the appearance of the arc.

PIN TYPE INSULATORS

21. *Inspection:*

All parts shall be inspected before assembling.

22. *Routine Tests. Electrical Tests Before Assembling:*

All insulator shells, before being assembled, shall be tested for three minutes at the voltages given in the following table. Should any shell be punctured in the last minute of test, the test will then be continued, after the removal of the punctured piece, until no puncture occurs in one full minute of test. These tests are to be conducted by inverting the parts in pans of water and placing water inside the several pieces, the potential then being applied to the two bodies of water.

Note. The water both inside and outside shall be filled to within one quarter of an inch of the highest point to which the later applied conducting parts, including cement, will extend.

The individual tests in the various shells shall be as follows:

Head..........................,	volts
Second Shell....................,	"
Third Shell.....................,	"
Fourth Shell....................,	"
Center.........................,	"

23. *Routine Tests—Final Electrical Test:*

All completed insulators shall be tested according to one or the other of the four following tests. One of these tests should be definitely specified for each lot of insulators tested under these specifications.

a. The insulators in groups shall be subjected to a voltage steadily applied just below the flash-over voltage for a period of three minutes. The voltage shall be held at such a point that a flash shall occur over some insulator of the set occasionally, but not more often than once in three seconds. This test involves a steady voltage stress and gives an opportunity for the heating up to the puncture point of any spots in the porcelain which may be sufficiently defective. For this test it is therefore objectionable that there should be frequent flashing over, as each flash-over presumably removes the potential from all insulators for one alternation.

If an insulator of the group punctures during the last minute of the test, the test shall be continued until one full minute elapses without a puncture.

b. The insulators in groups shall be subjected to a voltage in excess of the flash-over voltage so that a continuous succession of flash-overs exists, this being continued for a period of two minutes. This test is intended to introduce the effect of impact and consequently continual flash-over is necessary.

c. The insulators in groups shall be given test (a) above, followed by test (b). The first test may be changed into the second by merely raising the potential without removing the voltage. In this case the time of the second part of the test should be reduced to one minute.

d. This test is the same as test (b) above, except that instead of applying this testing to insulators in groups, the insulators shall be tested singly and the voltage continued for a period of 20 seconds.

NOTE. In all the tests (a), (b), (c) and (d), above, it is important that the current be so limited in volume that no power arc shall follow a flash-over, as otherwise the voltage will be substantially removed from the insulators during the continuance of the power arc.

24. *Design Test—Mechanical:*

The following design test shall be made on enough complete insulators, usually not exceeding $\frac{1}{4}$ of one per cent, to determine the behavior of the design and the uniformity of the product.

The insulators shall be capable of withstanding for 15 seconds without signs of distress a pull of.................... lb. (.................... kg.) applied at the tie-wire groove in a direction at 90 deg. with the axis of the insulator and pin. For the purpose of making this test, the insulator shall be mounted on the pin to be used in service. In case of failure the question as to whether the insulator or the pin is at fault shall be determined by testing again with a solid steel pin turned from a piece of round steel of such dimensions that this piece of steel acting as a pin for the insulator will not bend under the above-mentioned load.

It is desirable that a number of insulators be tested to destruction to show approximately the margin in mechanical strength.

25. *Design Tests—Electrical:*

The following design tests shall be made on enough complete insulators to determine the performance of the type. The insulator shall stand without failure:

a. A test for *flash-over, dry,* of three times the potential between line wires, applied for one minute.

b. A test for *flash-over, wet,* of not less than two times the potential between line wires, applied for one minute.

c. Puncture test under oil shall be made as specified under §19 above.

SUSPENSION TYPE INSULATORS

26. *Routine Tests—Electrical Test Before Assembling:*

All insulator shells shall be tested according to one or the other of the three following tests. One of these tests should be definitely specified, for each lot of shells tested under this specification.

a. The shells in groups shall be subjected to a voltage steadily applied just below the flash-over test for a period of three minutes. The voltage shall be held at such a point that a flash shall occur over some shell of the set occasionally but not more often than once in three seconds. This test involves a steady voltage stress and gives an opportunity for the heating up to the puncture point of any spots in the porcelain which may be sufficiently defective. For this test it is therefore objectionable that there should be frequent flashing over, as each flash-over presumably removes the potential from all insulators for one alternation.

If a shell of the group punctures during the last minute of the test, the test shall be continued until one full minute elapses without a puncture.

b. The shells in groups shall be subjected to a voltage in excess of the flash-over voltage so that a continuous succession of flashes exists, this being continued for a period of two minutes. This test is intended to introduce the effect of impact and consequently continual flash-over is necessary.

c. The shells in groups shall be given test (a) above, followed by test (b). The first test may be changed into the second by merely raising the potential at the end of the first test. In this case the time of the second part of the test should be reduced to one minute.

Note 1. In all the tests (a), (b) and (c), above, it is important that the current be so limited in volume that no power arc shall follow a flash-over, as otherwise the voltage will be substantially removed from the shells during the continuance of the power arc.

NOTE 2. In making these tests the insulator shells are to be inverted in a pan of water and water placed in the inside. The water both inside and outside shall be filled to within one quarter of an inch of the highest point to which the later-applied conducting parts, including cement, will extend.

27. *Routine Test—Mechanical Test:*

After at least ten days setting of the cement, all units shall withstand for 3 seconds without signs of distress a mechanical pull of .... lb. (............... kg.), in line with the axis of the insulator. Insulators may be given this test after a shorter period of setting, at the risk of the maker.

28. *Routine Test—Final Electrical Test:*

All completed insulator units shall be tested according to one or the other of the four following tests. One of these tests should be definitely specified for each lot of insulators tested under this specification.

a. The insulator units in groups shall be subjected to a voltage steadily applied just below the flash-over test for a period of three minutes. The voltage shall be held at such a point that a flash shall occur over some unit of the set occasionally but not more often than once in three seconds. This test involves a steady voltage stress and gives an opportunity for the heating up to the puncture point of any spots in the porcelain which may be sufficiently defective. For this test it is therefore objectionable that there should be frequent flashing over, as each flash-over presumably removes the potential from all units for one alternation.

If a unit of the group punctures during the last minute of the test, the test shall be continued until one full minute elapses without a puncture.

b. The insulator units in groups shall be subjected to a voltage in excess of the flash-over voltage so that a continuous succession of flashes exists, this being continued for a period of two minutes. This test is intended to introduce the effect of impact and consequently continual flash-over is necessary.

c. The insulators in groups shall be given test (a) above, followed by test (b). The first test may be changed into the second by merely raising the potential at the end of the first test. In this case the time of the second part of the test should be decreased to one minute.

d. This test is the same as test (b) above, except that instead of applying this testing to units in groups, the units shall be tested singly and the voltage discharges continued for a period of 20 seconds.

NOTE. In all the tests (a), (b), (c) and (d) above, it is important that the current be so limited in volume that no power arc shall follow a flash-over, as otherwise the voltage will be substantially removed from the insulators during the continuance of the power arc.

This test shall be made after the mechanical test above prescribed, §27.

29. *Design Tests—Electrical:*

The following design tests shall be made on enough complete assembled insulators, not exceeding $\frac{1}{4}$ of one per cent, to determine the performance of the type.

a. A test for *flash-over*, *dry*, of one insulator unit having its normal position in the string and of a complete insulator string consisting of .... units, of .... volts, and.......... volts respectively, applied for one minute.

b. A test for *flash-over*, *wet*, of a single insulator and of the string, of . . . . . . volts and . . . . . . volts respectively, applied for one minute.

c. The puncture test under oil shall be made as specified under §19 above.

It is preferable that the arc-over of the complete insulator when the test voltage is sufficiently raised shall be over the insulator as a whole and shall not be over the individual elements.

30. *Design Tests—Mechanical:*

The following design test shall be made on enough complete insulators, usually not exceeding $\frac{1}{4}$ of one per cent, to determine the behavior of the design and the uniformity of the product.

After at least two weeks setting of the cement, the insulators to be tested shall withstand for 15 seconds without signs of distress a pull of .... lb. (................ kg.) in line with the axis of the insulator.

It is desirable that a number of these insulators be pulled to destruction to show approximately the margin in mechanical strength.

APPENDIX

The following tests are recommended as desirable where appropriate. They are not incorporated in the above specifications as experience with them is not yet sufficiently broad.

31. *Uniformity Puncture Test:*

Twenty-two single insulators, chosen at random from stock, which have passed all routine tests, shall each in turn be punctured under oil as provided for oil tests in §19 above. Any twenty of these values of puncture voltage shall then be selected by the maker. The difference between the maximum and minimum of these twenty puncture voltages must not be more than 20 per cent of the average voltage. This test should be repeated with one or more additional groups of 22 disks, not exceeding in the aggregate $\frac{1}{4}$ of one per cent of the total, enough to determine the uniformity of the product. In case of failure of the lot to pass this test, the other insulators from the same burnings shall be tested as specified under §28, but for a period 5 times that there specified.

32. *Design Test—Impulse Test:**

Some form of impact or high-frequency test is of the greatest importance in testing high-voltage insulators, at least for the design tests. Two or three forms of such tests have been proposed, and it is expected that a supplement to this specification will be issued when these tests have been sufficiently standardized.

33. *Design Test—Combined Mechanical and Electrical Test:*

The following design test should be made upon enough insulators to determine the performance of the design and the uniformity of the product.

An insulator placed in an insulated testing machine and impressed with a voltage just under or just over the flash-over voltage (as may be agreed upon), shall be subjected to a gradually increasing mechanical pull until puncture occurs.

The insulator should not puncture at less than twice, or, preferably, three times the maximum pull to which the insulator is to be subjected in service, as fixed in §6 above.

34. *Uniformity—Brittleness Test, Applicable Especially to Suspension Insulators:*

The following uniformity test should be made upon enough insulator units to determine the performance of the design and the uniformity of the product.

A completed insulator unit which has passed all routine tests shall be placed in ice water and the temperature of the water raised to boiling. The heating should not begin until after the insulator has been in ice water 60 minutes to permit all parts to come to the same temperature. The water should then be heated at a uniform rate of about one degree cent. per minute. After remaining at boiling temperature for 30 minutes the unit may be removed and should afterward be tested either by the measurement of its insulation resistance, using one or two thousand volts for the measurements, or by the standard routine electrical test (§28), or both.

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*For an example of the application of such a test see paper by Imlay and Thomas, TRANS. A. I. E. E. Vol. XXXI, 1912, p. 2121.

35. *Percentage of Failure in Routine Tests.* The percentage of punctures in the electrical tests is a rough measure of the burning of the porcelain and the care in manufacture. A relatively large percentage of failures, perhaps over 5 per cent, suggests under-firing. It is recommended that the following modification be applied to routine tests §23 and §28:

"When the percentage of punctures in any group of insulator units or shells under test simultaneously, exceeds 5 per cent, the length of the time of application of the test voltage shall be doubled for that group".

DISCUSSION ON "SPECIFICATION FOR INSULATOR TESTING—COVERING INSPECTION AND TESTS OF HIGH-TENSION LINE INSULATORS OF PORCELAIN, FOR OVER 25,000 VOLTS" (ENGINEERING DATA SUB-COMMITTEE), DETROIT, MICH., JUNE 25, 1914.

Percy H. Thomas: Last year, the High-Tension Transmission Committee presented a "sample" or "model" or "skeleton" specification, as it might be called, for the testing and inspection of high-tension porcelain insulators. This has been quite extensively remodeled during the present year, without greatly changing the fundamental ideas of the specifications. Presumably this discussion will be the last chance for any effective criticism. I wish to open the subject by giving a few words of explanation in answer to a number of the suggestions which have been made.

I will call attention first to the fact that the high-tension insulator industry has developed under existing conditions, until at the present time it has reached large proportions. These insulators are all tested and used according to certain customary methods which are now well understood and generally accepted. It is not practicable for the Institute to step in and pass a resolution saying that hereafter the industry shall change about and follow some specification which it would present, radically different from the former practise. If our specification is to be used at all, it must be close enough to present methods, so that it can be followed without upsetting the general practise of the industry. This is our first limitation.

The second limitation is the fact that the manufacturers of insulators have their own electrical testing apparatus and mechanical testing apparatus, and it is only a very small percentage of the insulators actually manufactured and used that are tested on any other apparatus. We now have in addition two or three laboratories, outside of the electrical manufacturing companies, where tests can be made, but they are not accessible to a very large number of the users of insulators, and our specification must be so drawn that it will fit into the particular installations of testing apparatus at the manufacturers' plants.

Another thing which limits the extent of change that may be embodied in the proposed specification is the fact that the tests which the purchaser usually makes on his insulators are an integral part of the manufacturing process of the manufacturing companies. The manufacturing companies rely on this inspection and test, to a large extent, to check up and eliminate and weed out the bad material from their product. We should draw our specification in such a way that this will continue to be the fact.

I will repeat, what perhaps you have forgotten, that the backbone of this specification was originally drawn by the engineers of one of the insulator companies. Mr. Peek also gave us a model specification. Most of the meat of Mr. Peek's specification was put over into the manufacturer's specification.

Perhaps the greatest value of this testing specification is the stating in definite form for the *average* engineer those particular facts, those broad methods, those general characteristics, which the most experienced engineers have found to be the most helpful in selecting and testing insulators. There is a good deal of educational matter in the specification that has been seriously objected to by a number of those who have favored us with criticisms, and I can understand their point of view—it goes against their sense of proper form for a specification on which materials are to be bought to include explanatory sentences and general statements, but, looking at the matter from a broad point of view and considering the practical results to be obtained, it seems to me these educational interpolations are a very important part of the whole.

There is great objection on the part of some to the use of the words "design test" to describe those tests which are made on a few insulators to determine the characteristics of the type, as distinguished from the routine tests made on every insulator. From a certain point of view the design should, as the critics claim, be determined before the test specification is adopted. However, the actual tests given in the specification as design tests should be made as called for in most cases, so that it reduces to a question of terms, and the term used is frequently used and I know of none better.

One of the suggestions that comes most frequently is that we specify the minimum size of transformer capacity that is safe for testing insulators. The necessity of using large-capacity transformers occurs only when comparative tests are to be made on different transformers or where for some other reason sine wave form is important. Ordinarily for routine tests it is desirable to limit the capacity of the testing transformer to prevent arcs on the insulators. The manufacturers of insulators have transformers of limited capacity installed, some of them of peculiar design from the point of view of power transformer design, and most of them use some means of limiting the capacity, either series resistance or series choke coils, or weakening the field of the generator.

Some one asked for a specification as to the quality of oil in which to make the oil puncture test, but I hardly think that is necessary. There is no trouble to get the insulator to puncture under oil, rather than flash over, and I cannot imagine that the quality of the oil would make much difference in the puncture quality of the porcelain.

I would call attention to the so-called combined electrical and mechanical test in the appendix. This test calls for the application of mechanical strain while the electrical potential is on. You will remember last year at Cooperstown Mr. Nicholson gave us some data showing that certain insulators punctured with less than half their normal puncture value when mechanical strains of less than half the ultimate strength were impressed upon them. The year past has shown an investigation of this matter and a very great improvement. The test is easily applied. One manufacturer has a wooden arm testing frame, and puts voltage on a single insulator, allowing it to flash over, or he applies the voltage just below the flash-over, as may be desired, and gradually brings up the mechanical pressure until the insulator punctures.

E. E. F. Creighton: During the last three years we have given considerable attention to this matter of testing insulators, and I wish to take it up from a different point of view from that of the committee. I think the specifications are very desirable in the form in which they are now presented—they are made, however, from the point of view of the man buying insulators, and I shall take the point of view of the man using insulators.

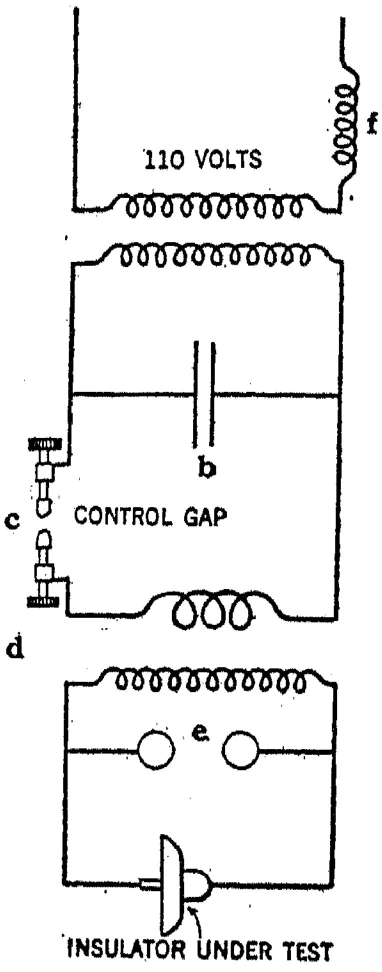

FIG. 1

Mr. Thomas has pointed out the difficulty that a user has in getting testing apparatus with which to test the insulators, the cost of it, and the details involved in carrying out the work. It was about one and one-half years ago, when a paper was presented on this subject in New York, that I had a very brief opportunity to show the oscillation transformer as a method of testing insulators, but the method has not been followed up in the proceedings of the committee—perhaps they lack definite information on the subject. I wish to give some instances of the use of this method, and point out some of its advantages. We started out with a problem such as many have at the present time—namely, the frequent loss of installed insulators. Forty of these insulators were removed from a line and taken to the laboratory, and there was applied to them a 60-cycle test, and four insulators punctured under this test at the flash-over potential. The 36 insulators left were then tested out with a high-frequency transformer and all failed. The diagram, Fig. 1, shows the well-known connections of an oscillating transformer set. The first circuit, at 110 volts, say, is stepped up to any convenient voltage, which I shall designate as 13 kv., which charges a condenser. The condenser sparks through an adjustable gap and coreless transformer. The coreless transformer gives a high potential at a high oscillating frequency. The insulator to be tested is connected across the high-voltage side of this transformer. The potential applied to the insulator is gradually increased by starting with the control gap very small and gradually screwing it open. By opening this gap carefully, any potential desired may be applied to the insulator at a frequency of several hundred thousand cycles per second, a convenient value being in the neighborhood of 200,000 cycles. The natural make-up of these transformers will give from 100,000 to 300,000 cycles. There is little need at present to question the proper value of this frequency, whether 100,000 or 200,000 cycles is to be used, because there has been such a tremendous step in going from 60 cycles to 200,000 cycles that an increase to 300,000 cycles is comparatively negligible in its effects. The higher the frequency the more the corona sparks follow the surface of the porcelain.

With apparatus of this kind we have made a great many tests in the porcelain factory itself, also the tests of insulators taken from lines and of insulators fresh from the manufacturers. In the early work it was feared that the test was too severe, and it was, since we did not take precautions at that time to bring up the voltage gradually by opening the control gap. It soon became evident that the voltage must be held under control and the adjustable control gap was therefore made an intrinsic part of the apparatus. An illustration of the value of the method is given by a series of tests which were applied to wet process porcelain bushings. Lots of one hundred bushings, as they came from the kilns, were tested on 60 cycles, bringing the potential up until it sparked over, then holding the potential a little below that value for one minute, and out of the one hundred there would be, as there always are, a few defective ones. They were then tested out on the high-frequency circuit. Going through different types of insulators, and insulators from different firings, there was a percentage of from zero to 17 per cent additional loss.

Another group of insulators was then taken, one hundred in a group, and tested on the high-frequency circuit first, and the defective insulators were removed as fast as they showed up. The insulators that were left after this high-frequency test were passed through a 60-cycle test; and although many hundreds of insulators were treated in that way, there was never a single case where an insulator which passed the high-frequency test was in any way damaged on the 60-cycle test. That, in itself, is proof sufficient that the high-frequency test is better than the 60-cycle test.

The next question arises—is it a fair test? At the present moment I am not going to discuss that, but simply say that the test can be made as reasonable or as severe as desired by the simple adjustment of the control gap. By opening the control gap to its widest value, super-spark potential may, of course, be thrown on the insulator and damage may result. For example, if the sparking potential of the insulator is 80,000 volts, it is easy enough to arrange the gap so as to throw on the insulator at the first instant a voltage of 175,000 volts. That value of voltage exists on the insulator during only the brief time necessary for the arc to creep around the surface from cap to pin. Such a severe test is not to be recommended as a standard test.

Testing just at and below the spark potential is both desirable and fair to porcelain of good design and material. This seems sufficient comment on the severity of test.

Every line at the present time has insulators on it that are old—perhaps only a dozen years old, but that is very old in the art of making insulators. At that time insulators were made very much like dinner plates, and very little attention was paid to the subsequent testing. I find that old insulators taken from a number of different systems are very liable to be in a condition that is sometimes designated as porous, due to underfiring. These insulators are necessarily weak electrically. The problem, then, of the operating engineers is not only how to buy good new insulators, but what to do with the old ones. It is usually impracticable to take down from the pole line all of the insulators and stand the loss which comes from mechanical accidents in handling and shipment to a laboratory to have tests made. Therefore, it is necessary for the engineers of a transmission company to be able to make tests, and not only make them themselves, but if desirable to make them on the insulators in place on the line. The oscillator form of testing, then, gives the possibility of having universally available a light, cheap and effective means of testing insulators, either new from the factory, or old, in service.

The question of kilowatt capacity for testing has been brought up by Mr. Thomas. In the oscillator sets the kilowatt capacity of the 60-cycle transformers is extremely small—1, 2 or 3 kilowatts—even a potential transformer has been used, although it cannot be used continuously, due to the overload. A very small kilowatt capacity in the 60-cycle circuit will sound unreasonable to those who contend that it is absolutely necessary to have a large generator and a large transformer in order to get reasonable results in testing, but that is not true in this case, for the actual power of this outfit, even with a small transformer, is considerably greater than any of the 60-cycle testing outfits that are in common use at the present time, without exception. The difference comes in this, that the energy is taken by the condenser at comparatively low power during a quarter-cycle of the generator wave. Although this period of time is of the order of 0.01 second, it is an extremely long time as compared to the time of discharge of the condenser. When the potential has risen to the maximum point of the 60-cycle wave, it breaks over the control gap. The full charge of the condenser will be given out at a rate which will depend upon the capacitance and the inductance of the oscillating circuit. As a matter of fact, the condenser is capable of giving out several thousand kilovolt-amperes for an instant, so there is no question about a sufficient kilowatt capacity.

In conclusion I wish to say one word in regard to one of the suggestions presented in the specifications, about uniformity—the valuable recommendation is that if a certain percentage of the insulators fail the entire lot should be rejected. This ruling can be more efficiently applied if the insulators can be divided into lots corresponding to definite zones in a kiln and to definite firings.

Percy H. Thomas: How do you determine the voltage and the frequency on the high side of the oscillation transformer?

E. E. F. Creighton: The frequency is measured either directly by cymometer or calculated, and the calculations agree so accurately with the measurements that the easiest method is by calculation. The cymometer is an instrument as easy to handle as a wattmeter. Once the method of use is learned it is easy to handle. In the matter of potential there is some question; there is no way today of accurately measuring high-frequency potential. The potential as given by the proposed standard sphere gap is assumed to be correct. The limitation designated by Mr. Peek is to make the length of gap not greater than three times the radius. That is the only basis we have for the direct measurement of high-frequency voltage. Practically it is simply a matter of what equivalent gap will spoil an insulator. The spark potentials at arc-over voltage for 60 cycles and 200,000 cycles agree closely, in general.

Percy H. Thomas: There is no question that this method Professor Creighton has been telling us about, and which he fully described and demonstrated at the December, 1912, meeting in New York, is a powerful instrument of research, but I doubt if he would consider that it is quite definitely enough established to embody in the specification.

E. E. F. Creighton: This is as definite a test as some which have been put in the specification. I refer to the impulse test. The impulse test has been made a part of the appendix, and this test which I have shown is far better understood and can be made less dangerous than the impulse test.

Percy H. Thomas: That leads to a point I want to bring out, as to the relative characteristics of the test Professor Creighton has described and the impact test called for in the specification. The difference is this—the impact test of the specification is a shock test, a feeble shock, applied to the insulator, almost exactly paralleling the condition of service brought about by lightning and switching. It shows, if properly carried out, no element of heating. This test referred to by Professor Creighton, is, if I am not mistaken, entirely dominated by the heating effect produced by the high-frequency current; what I mean to say is this—when we have a high potential impressed on any insulator, the material of the porcelain is subject to an extreme pressure. Every time that test is reversed, a new element of heat is added. With the 300,000 cycles, you have 300 times the amount of heat generated, due to the expansion of material, that you do in the single shock. The net result is not only the heating of the insulator, but the heating of the air in the particular place where the interruption of potential is greatest. I do not think you realize how quickly the dielectric strength of porcelain goes down as the temperature goes up. I cannot give definite figures. Two or three times the boiling point of water is enough to make a great difference in the insulation resistance of porcelain. It is the extent and degree of the heating of the dielectric material at that high frequency which is, it seems to me, the thing we must know more about before we can use this test. In actual service we do not get that condition—we get two or three impacts, but never sustained high frequency. It is putting a great premium on efficiency in a thing which, while it may be indirectly related to the serviceability of the insulator, is not necessarily related to it.

E. E. F. Creighton: I feel that this criticism is unjust, because it cannot be shown where the heating comes in. We can take an insulator of this kind and place it under the oscillation test for a whole minute, and all the time the spark discharges are streaming over the porcelain surface. It looks hot while the sparks are playing, but no appreciable rise in temperature is noticed after such a test by placing the hand on the surface. There is no doubt that a continuous strain applied at one point will heat the insulator. If one of these insulators is subjected to the continued voltage of an Alexanderson generator it is possible to make it red hot, but the application of the oscillator is different. There is a relatively long interval of rest between successive applications of high-frequency trains. The high potential is applied for a very small fraction of the total time. Judging from the many hundreds of tests we have made, I feel that the heating of the insulator, except in air spots where it is weak and where it ought to be heated, is entirely a negligible quantity.

Edward Bennett: I want to endorse most heartily what Mr. Creighton has said about the desirability of using impulse test circuits having such constants that fairly definite ideas can be formed of the rate at which the voltage across the insulator rises, and of the frequency of the applied stress across the insulator, provided the insulator under test does not flash over during the first half-cycle of the high-frequency oscillation.

The objection to the type of impulse circuit shown in Fig. 1 of the specification is that from the dimensions of such a circuit one can not determine very accurately the rate at which the potential rises across the insulator. This uncertainty arises from the fact that in the circuit shown in Fig. 1 in the specification,* even when used with fixed inductance, capacity and setting of the gap *A*, the rate at which the voltage rises across the insulator will depend upon the variable capacity of the different types of insulators under test. Suppose, however, that the type of circuit which Mr. Creighton has suggested is slightly modified by connecting across the secondary of the oscillation transformer, and in parallel with the insulator under test, a condenser having a capacity five or six times that of the insulator, as shown in Fig. 2 herewith. From the setting of the gap and the dimensions of such a circuit, one may compute with a satisfactory degree of accuracy the manner in which the potential will rise across the insulator up to the instant at which breakdown or flash-over occurs.

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*This diagram is not included in the revised specification.

A slight modification of the simple series circuit of Fig. 1 of the specification would eliminate the uncertainty due to the variable and unknown capacity of the different types of insulators under test, and would seem to render this circuit more satisfactory than the oscillation transformer connections advocated by Mr. Creighton. The modification of Fig. 1 of the specification is shown in Fig. 2. It consists in connecting the insulator under test in parallel with another plate condenser having a capacity about five times that of the insulator. The capacity of the 12 in. by 12 in. triple-petticoat insulators used on 40-kv. lines is about 2×10^{-11} farad from line wire to pin, and the capacity of a 10-in. single-piece suspension unit is about 3×10^{-11} farad from metal to metal. That is, the combined capacity of the condenser *B* and the insulator ought to be about 10^{-10} farad or approximately the same as the condenser *C*.

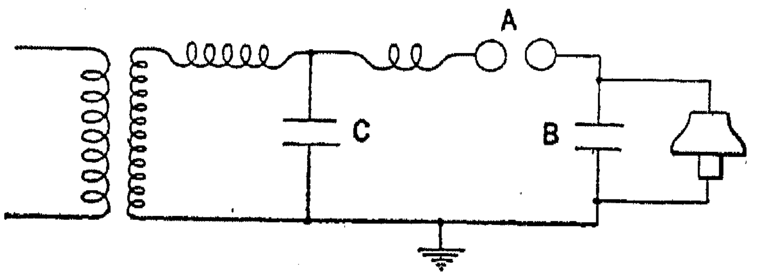

FIG. 2

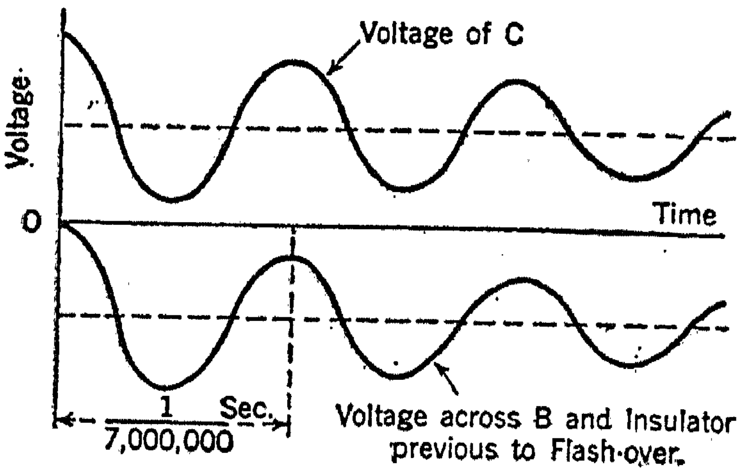

FIG. 3

If the coil *L* and the leads consist of about 30 ft. (900 cm.) of heavy copper, the inductance of the oscillatory circuit may be estimated at 0.01 millihenry. Such a circuit up to the instant of failure of the insulator will have a frequency of oscillation of approximately 7,000,000 cycles per second and the relation between the condenser voltages and time up to the instant of insulator breakdown will be as illustrated in Fig. 3. It is to be noted that the insulator, if it does not flash over during the first half-cycle, will be subject to a unidirectional pulsating voltage and not to an alternating voltage.

E. M. Hewlett: I would like to hear some discussion on the subject of the absorption test. Could not something in the nature of a year's guarantee be required? I have found insulators to fail from imperfect vitrification, which had passed all the different kinds of tests. Some of them fail in the course of a year, or six months, even, showing they have not been thoroughly vitrified, and still, to begin with, they will stand all the different tests. Until there is a test which will show definitely whether an insulator has been throughly vitrified, it would seem as though the insulator should come under the same kind of guarantee as a piece of machinery, as they are very often used in connection with the switching devices, to support busbars, etc., and should be considered as machines in that case.

Farley Osgood: In our somewhat extended system of multiple operation of transmission lines, fed by large-capacity generating stations operating in parallel, we learned from our charted data on service interruptions that the chief initial cause was the insulator. All testing at normal pressure (13,000 volts) brought us no real knowledge of our difficulty, so testing apparatus for more than three times normal voltage (40,000 volts) with 1000-kw. capacity was installed. Tests with this taught us no more than we could learn with line voltage testing, so we had made a testing outfit which, by means of a Tesla coil and condensers, gave us a frequency approximating 250,000 cycles.

We brought in from our lines samples of all types of insulators in service, fifteen types in all, several of which were designed for operating at three times the voltage on which they were being used, and all but two types failed under our test, meaning that the insulator would puncture before it would arc over, and the two types which showed reasonable results were not the insulators designed for higher voltage than the service in which they were placed.

Our high-voltage, large-capacity transformer would not develop this information, and only with the high-frequency testing outfit could we get the results which taught us that our insulators were wrong in design, in spite of the fact that they were the types specified by the manufacturers for the service, and met all the manufacturer's test guarantees.

The result of our work has been a new standard insulator for our 13,000-volt service which is about the same size as our original insulator but has thicker petticoats and which will spill over before it will puncture.

An analysis of our difficulties showed that unquestionably our troubles were caused by the effect of switching, which takes place frequently in a large system with big stations in parallel, and which effects were from high frequencies, and therefore we feel that the high-frequency test is the most useful one of all. It is the test which tells the operating man what he wants to know, and should be made in addition to any other tests that a manufacturer thinks necessary to establish the mechanical perfection of his product, as the high-frequency test is really one on the design of the insulator, rather than its structure.

We now give every insulator a high-frequency test before it is placed in service, and a recent test of 13,127 pin type insulators showed a failure of 1.75 per cent, and of 2260 disk type 3.94 per cent of failure. While at first this may seem high, it is not really so, as the actual value of the insulators destroyed is small, and well worth while for the insurance of continuity of service.

The test is not expensive, is safe, and a crew of four men from the line department, with one laboratory man to handle the test set and keep the records, can unpack, test, and repack 1200 insulators in an eight-hour day.

The high-frequency test, using the Tesla coils, we believe presents the following advantages:

1. An even distribution of corona over the entire surface of the insulator, searching out imperfections.
2. Failures under test are absolutely definite, being readily recognized by
   (a) cessation of corona,
   (b) abrupt change of tone of spark due to shortened path,
   (c) steady discharge through point of failure.
3. The test does not require skilled labor, but can be conducted by anyone, after a little training, if his sight and hearing are normal.

We believe we have at last an equipment which can be made portable for use in the field in testing individual insulators in service without removing them from the line, the transmission voltage, of course, being removed, and we advise operating engineers to learn of the benefits to the service to be derived from such testing, by themselves, in addition to any test, or any guarantee, of any manufacturer, no matter what the type or line voltage of the insulator.

S. C. Lindsay: I want to take exception to what Mr. Thomas said about the impulse test being usually sufficient for insulators tested with high frequency. That test is not sufficient on delta-connected lines having no ground. Two disturbances occurred within the past year on the system with which I am connected, where arcing grounds lasted for two or three minutes, and several insulators were punctured each time. I should think it would be well to retain the high-frequency test so that insulators will meet these conditions.

Percy H. Thomas: They might get some sustained effect from the arcing ground—I do not know just how that would work out.

John B. Fisken: It occurred to me that I might give some information bearing on the subject of the rain test. I had occasion once to demonstrate that there was no danger to a person holding the nozzle of a fire hose, the stream from which was striking a line operating at 60,000 volts. While I was demonstrating that, I went a little further and tried to break down some of the insulators by spraying the stream on them. I hit every part of the insulators I could reach with that stream, and there was not the slightest sign of any breakdown. That satisfied me that a rain test was entirely unnecessary.

F. W. Peek, Jr.: Considerable has been said about "high frequency" testing and the effects of "high frequency" on insulators and insulation. Under this term are included without discrimination, continuous high frequency as from a generator, trains of oscillations from a Tesla coil, single impulses of exceedingly steep wave front as from lightning, etc. The effects of these are entirely different. As the results of tests are all attributed to the same cause, " high frequency," there is naturally much confusion.

As an illustration, take an ordinary single suspension insulator unit with an arc-over voltage of 90 kv. and a puncture voltage of 120 kv. (under oil) at 60 cycles. If a continuous high frequency at 10 kv. and 100,000 cycles is applied from an alternator, the insulator will soon become hot because of dielectric loss, and crack. The destruction of this insulator is due purely to heating. If trains of high-frequency oscillations at the rate of about 100 trains per second are applied, arcs will play over the surface of the insulator if the voltage is sufficiently high. To cause the unit just to arc over, a voltage somewhere between 90 and 130 kv. (higher than 60-cycle arc-over) will be required. A sufficiently long application will cause the insulator to break down. An oscillatory voltage of say 200 kv. may be applied. The discharge over the surface will be heavier. Breakdown will occur in a very short time, due to over-voltage. This voltage is higher than the 60-cycle puncture voltage. Although this unit arcs over, it takes a finite but very small time for the air to break down and the arc to occur as each wave train starts. The time is too small for the porcelain to break down on one wave train. It is injured, however, and the effect is accumulative. A sufficient number of trains causes breakdown. If an impulse of very steep wave front, of say 500 kv., is applied, arc-over occurs along the surface. Perhaps ten such impulses may be applied without apparent damage. At the eleventh impulse breakdown occurs. Each impulse has caused damage during this very short time that it takes the arc to occur. A needle gap set at 150 kv. across the insulation to " limit " the voltage will not prevent ultimate breakdown. The various and apparently inconsistent effects due to " high frequency " are thus not altogether mysterious.

Such tests are extremely valuable as design tests, uniformity tests, etc., but great caution is necessary and a thorough understanding of what sort of " high frequency " it is, when these tests are applied to insulators that are later to be used on lines, as the first lightning stroke may be in effect the ninth or even the eleventh impulse noted above.

Many failures undoubtedly do occur, due to "high frequency," but there is at present too much of a tendency to use this explanation when the real cause is quite simple, perhaps only a mechanical one. A great many insulator failures, perhaps most of them, are *fundamentally* caused by mechanical cracking gradually taking place, due to poor mechanical design, internal strains, etc., or absorbed moisture. Naturally, failure occurs on these *weakened* units during a voltage rise, as by lightning impulse. Of course there are also some failures due to the accumulated effects of over-voltage impulses on good units.

I believe that most moderate-voltage lines, 20 to 60 kv., are under-insulated. These lines extend out into open country and are subjected to the same lightning voltages as the very high voltage lines. The insulators have the same factor of safety as the high-voltage lines, but in terms of operating voltage. This naturally is without meaning, as, assuming good insulators at the start, destruction is not caused by line voltage but by lightning. I have illustrated this further with a definite example in a discussion at the Pittsfield meeting, May 29, 1914.

Farley Osgood: We believe that an insulator should spill over before it punctures, giving the line the accompanying relief from the strains of switching changes which are constantly taking place; and an insulator of this type will act as an arrester on the line, as it were. The operating man wants his system to come back intact after severe strains, and much prefers the chance of a momentary interruption of service to the almost certain discomfort of the shake-up resulting from complete insulator failures.

Therefore, in this belief we feel that the high-frequency test is the only one which will assure the operating man that the insulator will perform as desired in this relation of spill-over to puncture.

We have proved that much can be learned from this test, that field work with such a testing outfit will anticipate many failures, and we have proved that it is cheap, and that it is safe.

In spite of all the theories to the contrary, such as we have just heard, I feel that the operating man has at last come into his own, in the matter of finding out some things about his insulators for himself, and doing it right at home, and I hope that the practicability of the results of these simple and easily made tests will be appreciated.

William B. Jackson: I want to ask a question relating to this matter, and that is, where the matter now stands, according to the researches and studies of the committee, in developing some suitable method of obtaining the capacity of the insulator, in the matter of mechanical shock, which has always seemed to be a rather important factor, although it has not been given very much consideration in tests.

Another question, which I presume has been studied by the committee, is whether there is any way by which the atmospheric effects may be accelerated in the passage of time upon the insulators. Guaranteeing an insulator for a year would be very small satisfaction, since insulators will run perfectly for two, three or as much as five years, and then break down.

Percy H. Thomas: The power of an insulator to hold a sustained load is now covered by a test in the specification, but I do not know any one who has proposed a test such as you indicate, and I do not know of any test that could be quantitatively expressed, so that an insulator would pass at 105 per cent and would not at 95 per cent. I do not know of any way by which we could approximate the effect of the weather. I wish we knew more of the effect of alkali dust, salt spray and condensation in connection with the rapid changes of temperature. These things are important, but we do not know the manner in which to produce such conditions beforehand.

William B. Jackson: They would be fruitful fields of study. In the case of cement, for instance, we have an impact test; in the case of concrete and cement, we have an acceleration test which is very valuable in the case of a building under construction. It seems that a study of that particular phase of insulators may bring good results.

Percy H. Thomas: The effect of electrical impact can be tested, but, mechanically, it is difficult to tell how the insulator will be affected.

Presented at the 31st Annual Convention of the American Institute of Electrical Engineers, Detroit, Mich., June 25, 1914, under the auspices of the Committee on Prime Movers.

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PRESENT STATUS OF PRIME MOVERS

BY H. G. STOTT, R. J. S. PIGOTT AND W. S. GORSUCH

ABSTRACT OF PAPER

The paper brings out in a concise form the present status of heat engines and hydraulic turbines in commercial use today for the conversion of the energy found in fuel and water into mechanical power for the production of electric energy.

The various types are compared as to relative importance, capacity, efficiency, weight, cost and economy, which are illustrated by curves plotted on kilowatt basis.

(a) Reciprocating Steam Engine.
(b) Steam Turbine
(c) Gas Engine
(d) Oil Engine
(e) Hydraulic Turbine
(f) Finance and Economics

Curves are plotted showing the investment and fuel costs of the different heat engine units, on the basis of percentage of normal full load rating of machines.

THE Committee on Prime Movers has selected the following subdivisions of its subject, in order to cover the most important recent developments in the field of prime movers:

1. Reciprocating steam engine
2. Steam turbine
3. Gas engine
4. Oil engine
5. Hydraulic turbine
6. Finance and economics.

In order to show the present status of the art in a graphic manner, practically all of the data obtained have been plotted in curves which appear in the appropriate place in the text.

RECIPROCATING ENGINE

The reciprocating steam engine has, during the past five years, become practically obsolete for use in modern power stations. In the large new central station this engine is not even considered; but in small isolated stations it is still used to a considerable extent, especially where heating service is also handled. In small sizes, the engine still has some advantage in economy over the small turbine, but the margin is getting continually smaller; some of the latest geared units being almost on equal terms. The non-condensing and bleeder turbines have offered a satisfactory substitute for the engine on heating service: the continuance of the engine in use is therefore chiefly due to the apparent inability of purchasers for isolated plants to realize that economy of steam is only one of the items constituting cost of power. The superior reliability, low maintenance, sustained original economy, and low attendance cost of the turbine generally overbalance the rather doubtful advantage in original economy of the small reciprocating engine.

STEAM TURBINE

The steam turbine is now at the head of the list of prime movers. The items of comparison with other prime movers are:

(a) Capacity
(b) Efficiency
(c) Weight
(d) Price.

Capacity and Efficiency. Usually the figure quoted as the measure of efficiency is the water rate or steam consumption per kilowatt-hour. Hardly any measure can be selected which is less satisfactory, since, unless the steam and vacuum conditions are stated, the water rate means nothing. Two turbines of exactly equal merits may be quoted as having very different water rates if one is operated on superheated steam with high vacuum, and the other wet steam and lower vacuum. To fix the merits of the design, a knowledge of the efficiency ratio (Rankine cycle) is necessary; and to fix the thermal efficiency, a knowledge of the steam conditions is needed—in other words, the heat drop available.

The water rate of a perfect Rankine-cycle engine is given as 3415 divided by the available adiabatic heat drop between initial and final conditions of the steam. Table I gives a few values for the commoner conditions in use. The efficiency ratio is equal to the Rankine-cycle water rate divided by the actual water rate of the turbine. The thermal efficiency and the water rate are both dependent upon the steam conditions, and can never be correctly compared except upon the same basis of pressure, superheat and vacuum.

The efficiency ratio is a measure of the goodness of the design, influenced somewhat by steam and vacuum conditions. The

TABLE I

Heat Drop and Water Rates for 100 Per Cent Rankine-Cycle Efficiency.

Press.	Dry steam.						100 deg. superheat.						150 deg. superheat.					
	28 in.		28.5 in.		29 in.		28 in.		28.5 in.		29 in.		28 in.		28.5 in.		29 in.	
	H.D.	W.R.	H.D.	W.R.	H.D.	W.R.	H.D.	W.R.	H.D.	W.R.	H.D.	W.R.	H.D.	W.R.	H.D.	W.R.	H.D.	W.R.
lb. per sq. in.	B.t.u. per lb.	lb. per kw.	B.t.u. per lb.	lb. per kw.	B.t.u. per lb.	lb. per kw.	B.t.u. per lb.	lb. per kw.	B.t.u. per lb.	lb. per kw.	B.t.u. per lb.	lb. per kw.	B.t.u. per lb.	lb. per kw.	B.t.u. per lb.	lb. per kw.	B.t.u. per lb.	lb. per kw.
165	324	10.52	338	10.09	355	9.61	345	9.89	360	9.47	378	9.03	353	9.66	368	9.27	387	8.82
190	331	10.30	348	9.80	364	9.37	356	9.58	369	9.25	387	8.82	365	9.35	379	9.00	398	8.57
215	341	10.00	354	9.63	371	9.19	363	9.40	376	9.08	394	8.66	373	9.14	387	8.81	406	8.41
240	347	9.83	361	9.45	378	9.02	371	9.19	385	8.86	403	8.46	380	8.98	396	8.61	413	8.24
kg. per sq. cm.	cal. per kg.	kg. per kw.	cal. per kg.	kg. per kw.	cal. per kg.	kg. per kw.	cal. per kg.	kg. per kw.	cal. per kg.	kg. per kw.	cal. per kg.	kg. per kw.	cal. per kg.	kg. per kw.	cal. per kg.	kg. per kw.	cal. per kg.	kg. per kw.
11.59	180.0	4.78	187.8	4.58	197.1	4.36	191.5	4.48	199.9	4.30	209.8	4.09	196.0	4.38	204.5	4.21	214.8	4.00
13.36	183.8	4.67	193.1	4.45	202.1	4.25	197.8	4.34	204.8	4.19	214.5	4.01	202.5	4.24	210.5	4.08	221.0	3.89
15.10	189.2	4.53	196.3	4.38	206.0	4.17	201.5	4.27	208.8	4.12	218.5	3.93	207.2	4.14	215.0	4.00	225.2	3.82
16.87	193.7	4.43	200.5	4.29	209.8	4.10	206.0	4.17	213.5	4.03	224.0	3.84	211.6	4.07	219.8	3.91	229.5	3.75

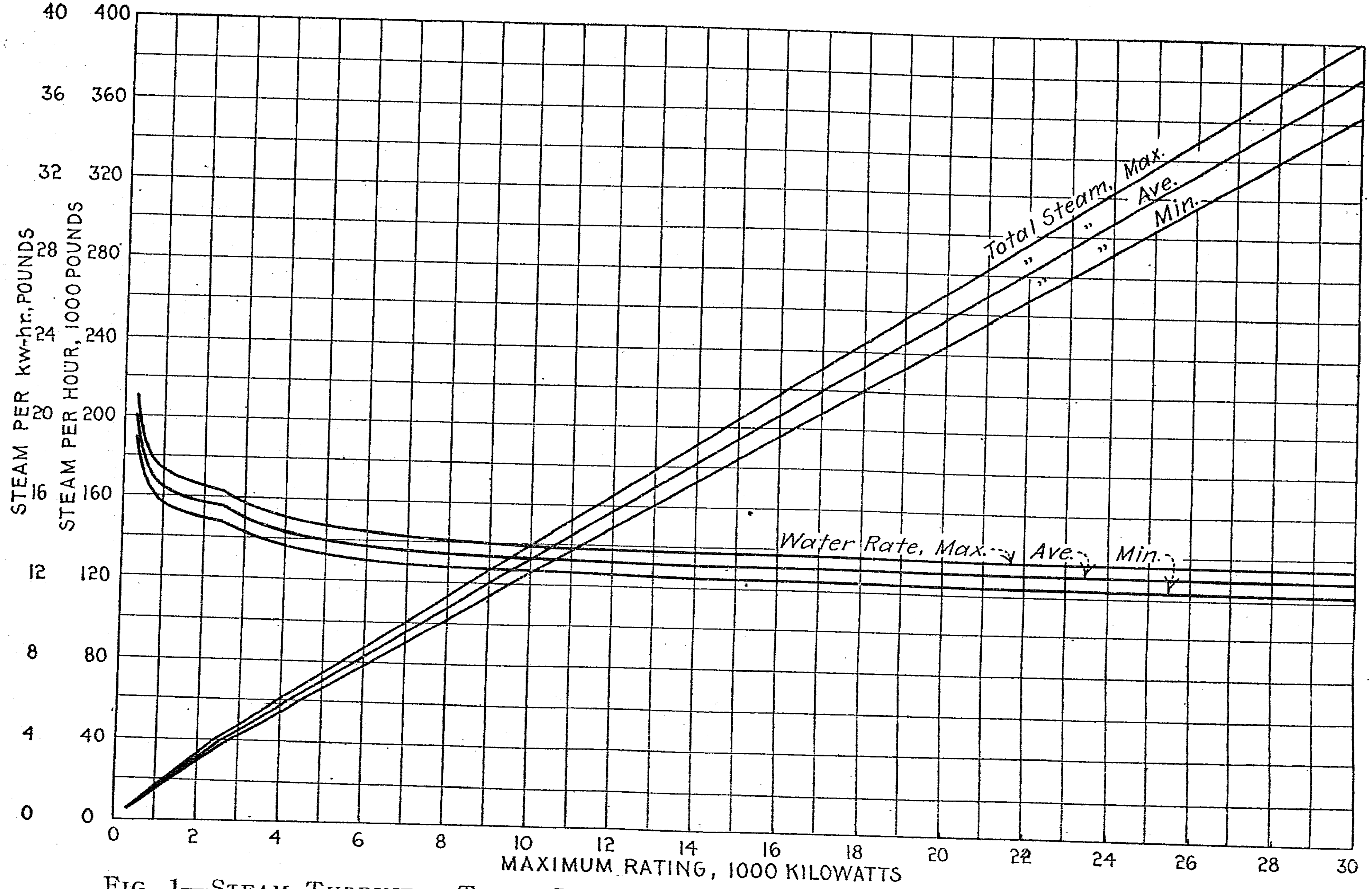

FIG. 1—STEAM TURBINES—TOTAL STEAM VS. CAPACITY—STEAM PER KW-HR. VS. CAPACITY
60 cycles, max. 24-hr. rating. 50 deg. cent. rise; power factor 80 per cent, pressure 175 lb., superheat 100 deg. fahr; vacuum 28.5 in.

efficiency ratios of modern turbines differ much less from each other than the variation of water rates would lead one to suppose.

The efficiency ratio increases (a) with size, (b) with superheat, (c) with reduction of vacuum down to about 26 in. (66 cm.), (d) with reduction of pressure. Speed also affects efficiency ratio, either to increase or decrease it, depending upon the design and conditions. Thermal efficiency increases (e) with pressure, (f) with superheat, (g) with vacuum. It is evident that some of these conditions at least are incompatible with each other, and that the turbine having the best water rate may not have the highest efficiency ratio.

Fig. 1 shows water rates which may be obtained for various sizes of machines. For the standard conditions of 175 lb. (79.3 kg.) gage, 100 deg. superheat, 28½ in. (72.4 cm.) vacuum, the average value is that which will ordinarily be obtained for standard designs; but better or poorer rates may be obtained under special conditions, either of design for high efficiency, which increases cost, or of cheap construction, which usually means poor water rate.

Fig. 2 shows the Rankine-cycle efficiency ratios under the same conditions. For the same sizes of machine, 25-cycle generators will have the same water rate and efficiency ratios, as the variation in speed can be readily cared for without sacrifice of efficiency. The corrections for other steam and vacuum conditions must be applied to get the proper water rates,—these differing somewhat for different types. The usual superheat correction is one per cent improvement in water rate for each 10 deg. superheat between saturation and 100 deg.; one per cent for each 12½ deg. superheat between 100 and 200 deg. superheat. The vacuum correction varies considerably with different machines, and amounts to about 5 per cent improvement between 27 and 28 in. (68.5 and 71 cm.); 6 per cent between 28 and 29 in. (71 and 73.9 cm.) A better method is to use the total heat drop available in each case as a ratio applied to the water rate. An important feature influencing cost is the matching of generator and turbine. In many cases the turbine has its best water rate at the maximum 24-hour rating of the generator. For many purposes this is undesirable. The best water rate should occur at from 75 to 85 per cent of the maximum 24-hour rating of the generator; in other words, the turbine should be smaller than the generator.

The overload devices (extra nozzles in the case of impulse turbines and by-passing in the reaction turbines) can be readily designed to take care of the loads up to 50 per cent in excess of the best water rate load in the turbine. The best water rate reached by the turbine occurs just before these overload devices operate; and it is for the steam flow at these loads that the turbine proportions are designed. When the effect of auxi-

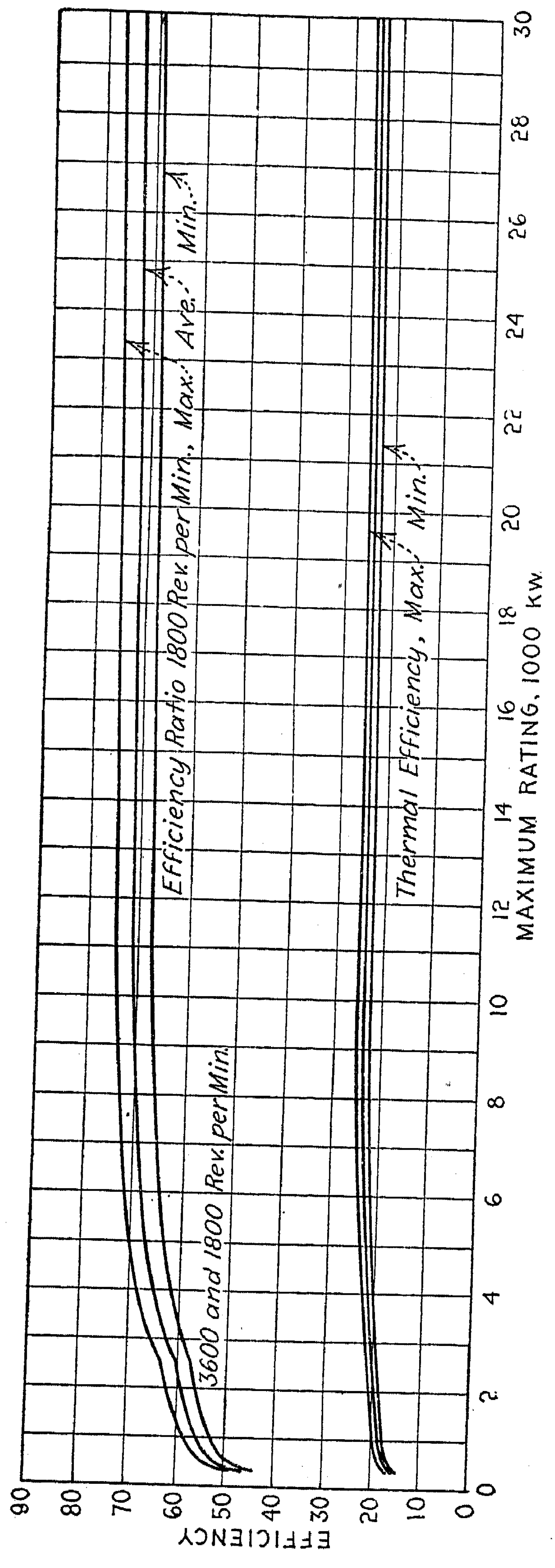

Fig. 2—Steam Turbines—Rankine-Cycle Efficiency Ratio and Thermal Efficiency vs. Capacity

Max. 24 hr. rating, 50 deg. cent. rise; pressure 175 lb.; superheat 100 deg. fahr; vacuum 28.5 in.

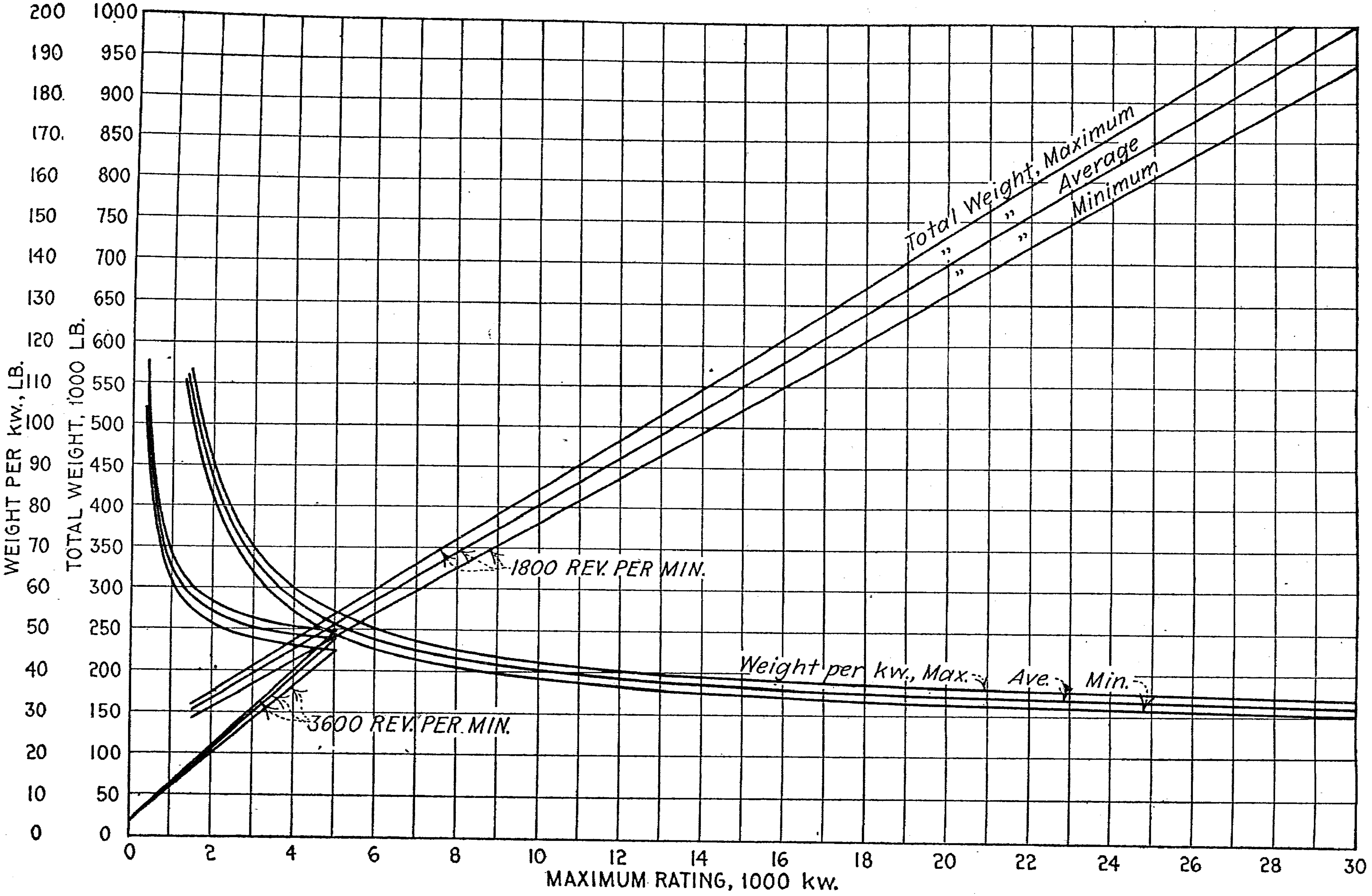

FIG. 3—STEAM TURBINES—TOTAL WEIGHT AND WEIGHT PER KW. VS. CAPACITY
60 cycles, max. 24 hr. rating, 50 deg. cent. rise; power factor 80 per cent, pressure 175 lb.; superheat 100 deg. fahr., vacuum 28.5 in.

liary steam consumption on the steam demand of the engine room is considered, it is evident that the under-sizing of the turbine to a small degree is desirable.

Weight. The weight increases with the increase of vacuum, decrease of speed, decrease of initial pressure, and increase of efficiency ratio. The increase of vacuum obviously affects the weight by increasing the size of the exhaust end and the blading. Decrease of speed increases the weight, as it enlarges the dimensions in every direction for a given capacity, and sometimes increases the number of stages for a given efficiency. Increase of efficiency ratio usually implies sharper blade angles, more stages, and larger blading, which obviously increases the weight. Fig. 3 gives the total weight and weight per kilowatt under the standard conditions previously stated.

Cost. The turbine design is usually a compromise between cost of manufacture and efficiency. The cost is influenced by steam conditions, speed, and by type, to some extent. Increased thermal efficiency means increased cost, as it means increased blade dimensions, stages, and exhaust openings for higher vacuum, and in some cases altered construction to suit higher superheats.

Fig. 4 is cost per kilowatt and total cost for machines built to the standard conditions previously given, delivered and erected within 600 miles of factory. 25-cycle machines will cost from 15 per cent more, in smaller sizes, to 10 per cent more in the larger sizes. Cost per lb. (Fig. 5) remains about constant for any given capacity, so that this increase in cost for 25-cycle machines is readily explained, as the reduction in speed from 1800 to 1500 and from 3600 to 3000 revolutions raises the weight approximately in inverse proportion to the decrease in speed.

The three items which influence the purchasing of a turbine are price, water rate and time of delivery. The time of delivery cannot be much reduced beyond a certain point. There is, therefore, a very strong tendency to cut the price or the water rate in order to get the business where competition is very keen. As only about one turbine in every 50 sold is ever tested, the opportunity to manipulate the water rate of the turbine downward has often proved a stumbling block to good engineering. The cost to manufacture any of the standard makes is not very different. The prices ordinarily will therefore be about the same. The tendency to cut the water rate below what can

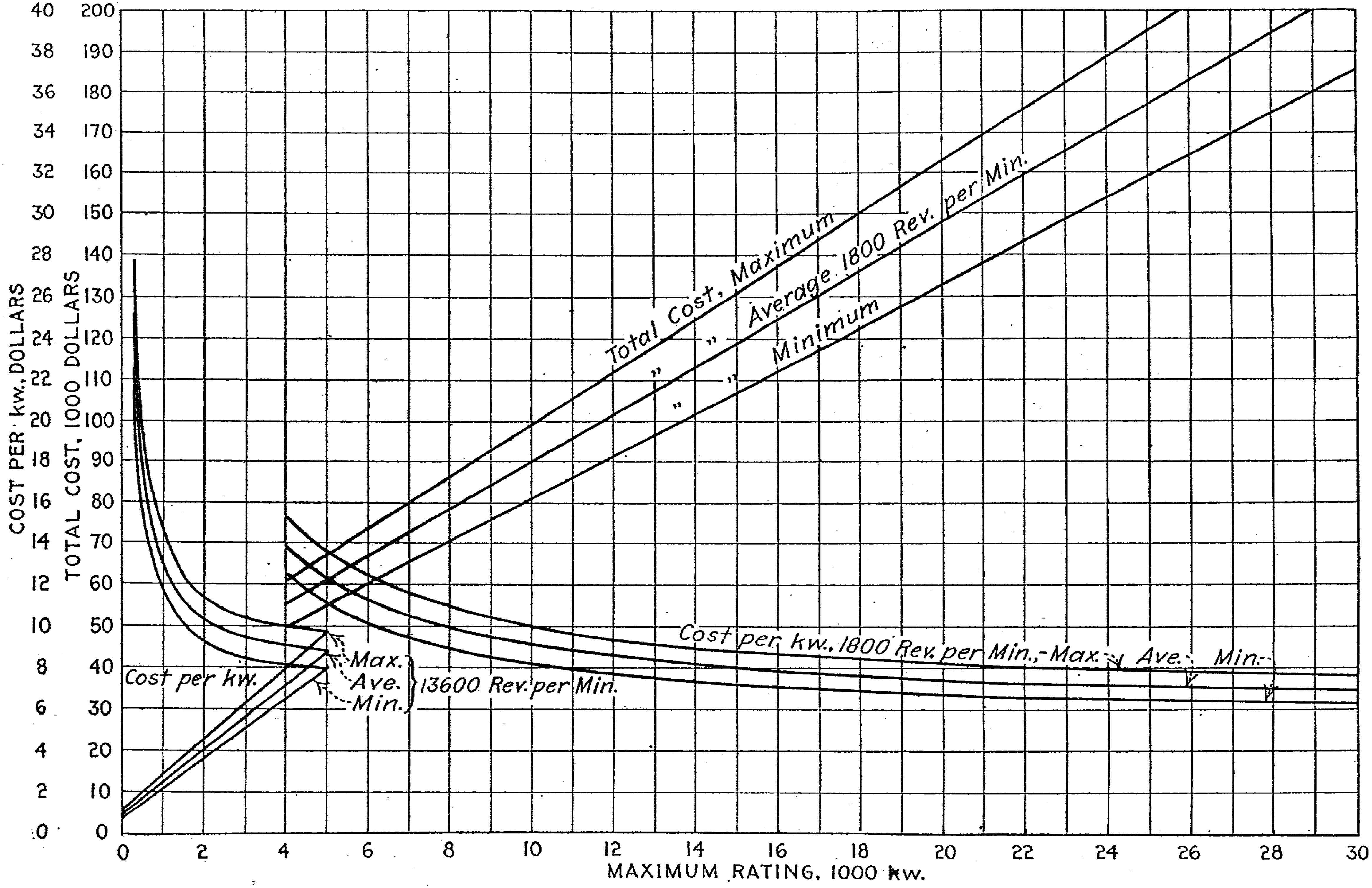

FIG 4—STEAM TURBINES—COST PER KW. VS. CAPACITY—TOTAL COST VS. CAPACITX
60 cycles, max. 24 hr. rating, 50 deg. cent. rise; power factor 80 per cent.; pressure 175 lb; superheat 100 deg. fahr.; vacuum 28.5 in.

actually be obtained can therefore only be checked by the engineer's watchfulness. Comparison with the Rankine efficiency ratio for any size machine is one of the safest means of detecting spurious water rates, since they will give impossible efficiency ratios.

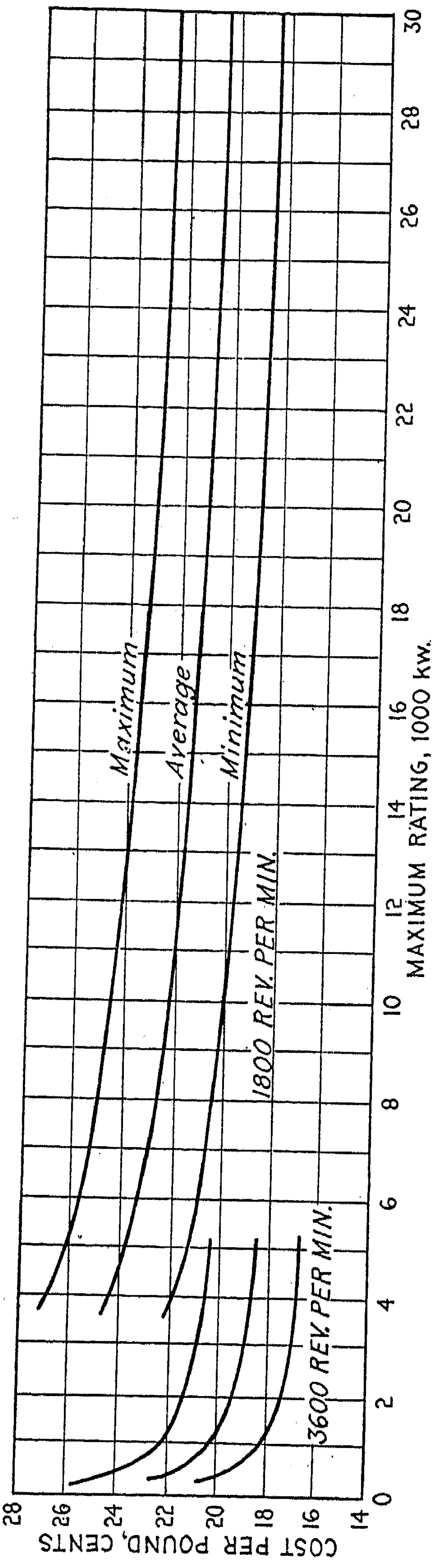

FIG. 5—STEAM TURBINES—COST PER LB. VS. MAXIMUM RATING

60 cycles, max. 24 hr. rating, 50 deg. cent. rise; power factor 80 per cent, pressure 175 lb.; superheat 100 deg fahr., vacuum 28.5 in.

GAS ENGINES

The fuel supply for the various classes of this type of prime mover is obtained either by the conversion of coal, coke, lignite, peat, wood, oil or other kindred fuels into a gaseous product in a producer; or from natural resources, or the recovery of waste or by-product gases from blast furnaces and coke ovens. The utilization of natural gas and blast furnace gas has enabled a wide application of the gas engine, amounting to over 75 per cent of the total gas power machinery installed in the United States, the natural gas being in the lead as to aggregate capacity.

The development of large gas engines is largely due to the ideal conditions existing in steel industries, where large quantities of blast furnace gas are available, requiring only cleaning to make a perfect fuel for this type of prime mover. Blast-furnace-gas power plants have been especially striking owing to the magnitude of the engine, which has now reached a capacity of 6000 brake horse power for a single unit of the twin tandem type.

The main improvements in gas engines have been in the reinforcement of cylinder castings, simplicity of the cylinder, piston and rod construction, more efficient packing, adoption of the throttling governors, etc.

The rapid introduction of the gas-producer in the manufacture of gas from cheap grades of coal has given special impetus to the producer gas engine. Many of the low grades of fuel which are not fit for use under the steam boiler have been used with reasonable success in the producer.

There is now a growing demand for gas engines to operate with coke oven gas, and probably interesting developments may be expected along this line within the next few years.

With the universal tendency toward high-speed rotative machinery, engineers engaged in the development of internal combustion engines have recently shown renewed activity in substituting rotary for reciprocating motion. While much valuable information has been obtained, yet the practical difficulties have not been surmounted and the gas turbine has not reached a commercial stage. However, if the gas turbine does come, it will probably revolutionize power production in large steel centers and wherever natural fuel oils abound in this country.

Capacity. There are two general types of gas engines known as the two-cycle and four-cycle, or two-stroke and four-stroke, built with single- or double-acting cylinders, either vertical or horizontal, the usual form in sizes above 200 brake horse power consisting of two double-acting cylinders set tandem. By combining two such units we have the twin tandem type that is built in sizes as large as 6000 brake horse power. The four-cycle engine is the type that is almost always used in units of any appreciable size, and especially the double-acting four-cycle type with two cylinders arranged in tandem, which was brought to a commercial state about eleven years ago.

Steam turbine and engine ratings are usually such that they are worked under their most economical load at the rating of the electrical generator. With gas engines, on the other hand, the efficiency increases with the load beyond the capacity of the engine (see efficiency curve, Fig. 6), and for this reason the rating of the engine is generally made as nearly as possible to its maximum capacity, allowing from 10 to 20 per cent for overload.

The gas engine does not possess inherent capacity for overloads in the same sense in which the steam turbine and engine do, hence whatever overload it has, is allowed by the manufacturer. The maximum capacity of a gas engine is evidently reached when the cylinder has taken a full charge of mixture of the highest heat value and density, that is, containing the maximum B.t.u.'s (large calories) per cu. ft. (0.028 cu. m.). This being the case, it is evident that gas engines must accommodate themselves to variations in the quality of the gas. Assuming for illustration, that a 10 per cent overload is sufficient, an engine of 550 horse power maximum capacity would then be rated at 500 horse power.

The gas engine being fairly limited as to the power which may be produced in a single unit, there has developed on the part of some manufacturers a disposition to increase speeds. While high speeds have been used in steam turbine and engine practise, it should not be taken as a criterion in gas engine work, as the heavy masses involved in the reciprocating parts of the gas engine may become destructive and the result may be higher maintenance cost.

Efficiency. One of the characteristics of the gas engine which other heat engines do not possess is that the thermal efficiency remains fairly uniform over all ranges of sizes.

Fig. 6 shows representative curves of thermal efficiency and rate of heat consumption per kilowatt generated, for different percentages of normal full-load rating, of large four-cycle producer and natural-gas engines, no allowance being made for auxiliaries.

Many figures have been given of the thermal efficiency of the gas engine which vary materially, but we believe that the curve above referred to gives conditions generally met with in large gas engines, namely, 25.2 per cent on the basis of brake horse power, or 23.8 per cent on the basis of kilowatt-hours generated at full load rating. All curves of the gas and oil engines have been referred to the basis of kilowatt-hours generated, so as to be comparable with the steam turbine and engine.

The range of fuel consumption as guaranteed by American manufacturers for their engines at full load rating with different fuels varies from 9500 to 13,500 B.t.u. per brake hp-hr. (2394 to 3402 large calories) for producer gas, and 8500 to 15,000 B.t.u. per brake hp-hr. (2142 to 3780 large calories) for natural gas, or reducing to basis of kw-hr., 13,500 to 19,200 B.t.u. per kw-hr. (3402 to 4838 large calories) for producer gas, and 12,200 to 21,400 B.t.u. per kw-hr. (3074 to 5393 large calories) for natural gas. Blast furnace gas runs in the neighborhood of 10,500 B.t.u. per brake hp-hr. (2648 large calories), or 15,000 B.t.u. per kw-hr. (3780 large calories) generated.

Weight. The operation of the gas engine involves high temperatures and pressures suddenly applied to the working parts, consequently this class of prime mover is inherently massive.

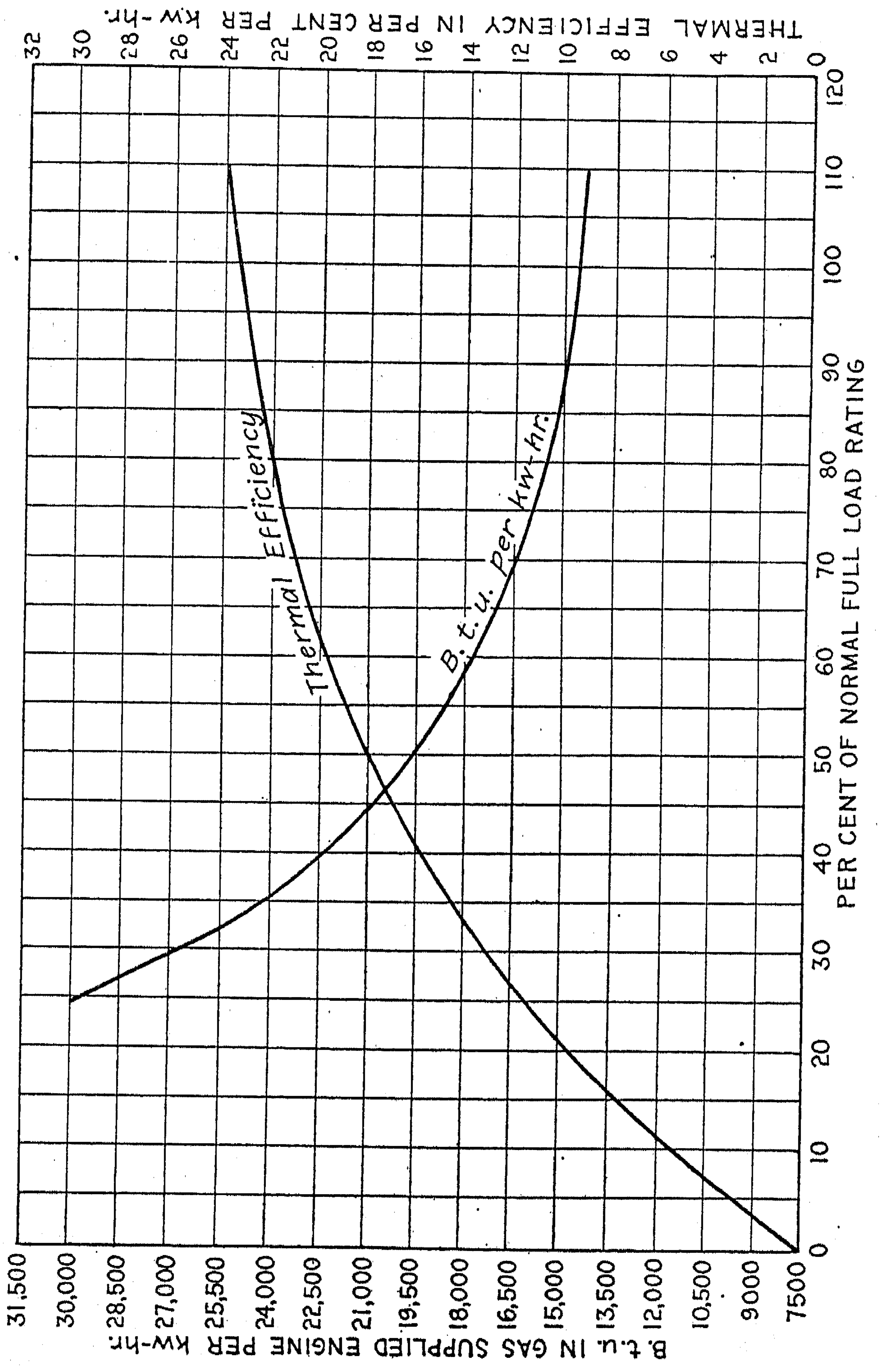

Fig. 6—Representative Curves of Large Gas Engines Using Producer or Natural Gas and Directly Connected to 60-Cycle Generator (auxiliaries not allowed for)

The range in weights of the various sizes of horizontal type producer-gas and natural-gas, four-cycle single- and double-acting tandem and twin-tandem gas engines, as manufactured by the largest gas engine companies in this country, is shown in Fig. 7.

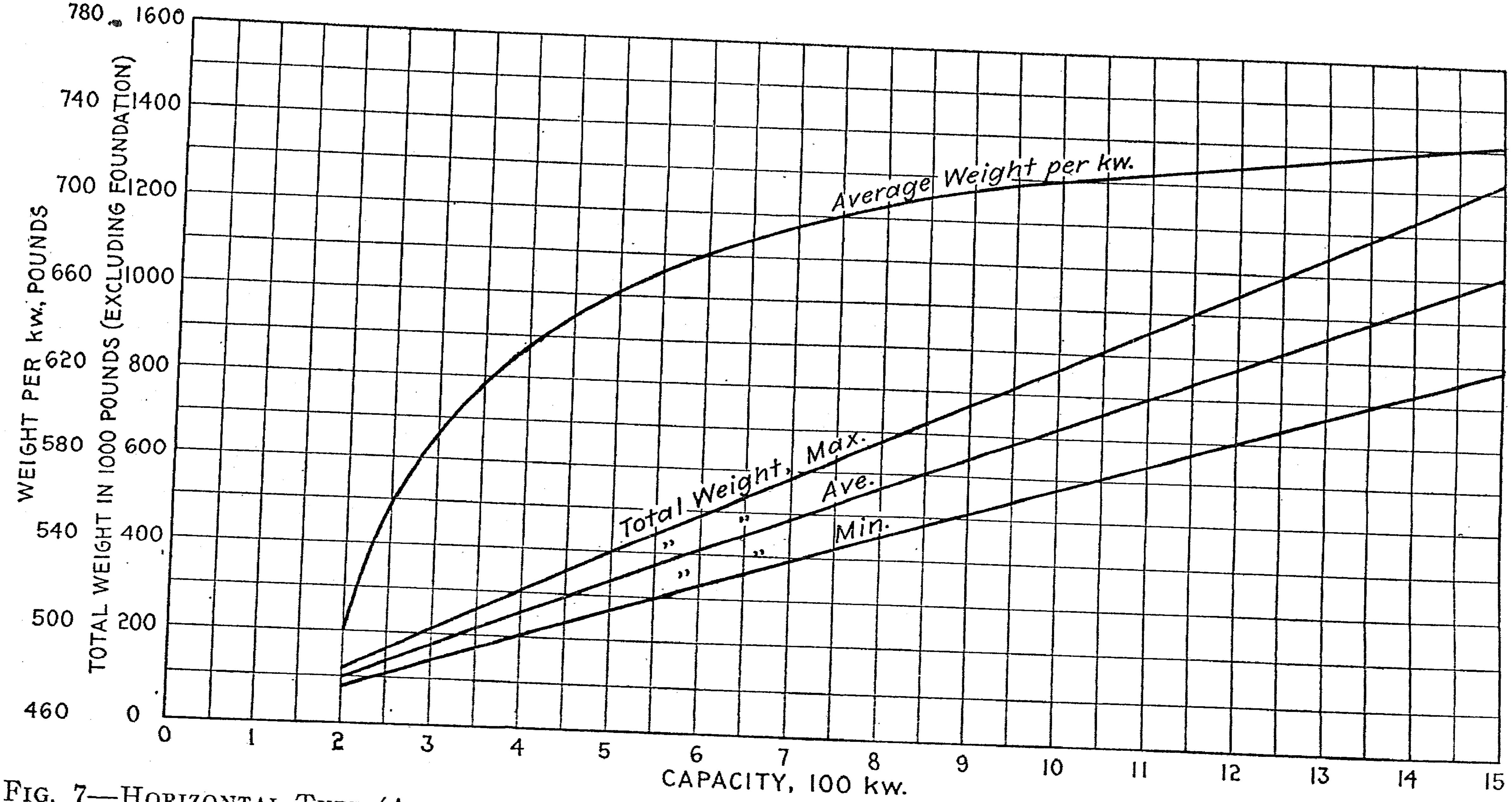

FIG. 7—HORIZONTAL TYPE (AMERICAN MANUFACTURE) PRODUCER GAS AND NATURAL GAS ENGINES, 4-CYCLE, TANDEM AND TWIN TANDEM, DIRECTLY CONNECTED TO 60-CYCLE GENERATORS FROM 200 TO 2000 KW. CAPACITY AT 80 PER CENT POWER FACTOR

These curves are drawn to include all capacities from 200 to 2000 kw., and show that there is a variation of 20 per cent from the average weight. Considering the curve of average weight per kilowatt, one thing is basic, namely, that the big unit weighs more per kilowatt than the small unit. The reason is that as you go up in size and lengthen out the stroke the weight runs up per unit capacity. The weight is governed by many considerations, such as rotative speed, the mean effective pressure on which the builder figures his rating, the nearest size the builder has to fit a given generator, the question of single or double crank, etc.

Cost. On account of the heavy parts made necessary by high temperatures and pressures, the gas engine is considerably more expensive to build than steam turbines or steam engines.

In some types of gas engines there is not very much difference between the cost per unit capacity in large and small sizes, whereas with other companies it varies considerably.

Fig. 8 shows the limits of total cost, average cost per kilowatt capacity, and average cost per pound, of the type and size of engine and generator as described in Fig. 7. The price is for engine and generator complete and installed, exclusive of foundations, within 600 miles of factory. It will be seen that the price varies 18 per cent from the average for the different types.

The cost of the gas engine is influenced by the same conditions that govern the weight, as explained above. The different combinations of stroke and synchronous speed result in varying piston speeds, and for a given power the price will be higher the lower the speed. Many attempts have been made to lower the cost of the gas engine by decreasing its weight without impairing its reliability, and to increase its capacity by increasing the pressure of the charge and simultaneous scavenging of the exhaust gases, but all without definite results.

OIL ENGINES

Oil engines have progressed rather slowly in this country, while in Europe the development has been more marked, especially since the expiration of the basic Diesel patents in 1912.

The Diesel engine is essentially a vertical type, but the last two years have witnessed a remarkable development of the horizontal type. While tests show that the fuel consumption is slightly higher than with the vertical type, nevertheless on account of the greater simplicity and better accessibility and

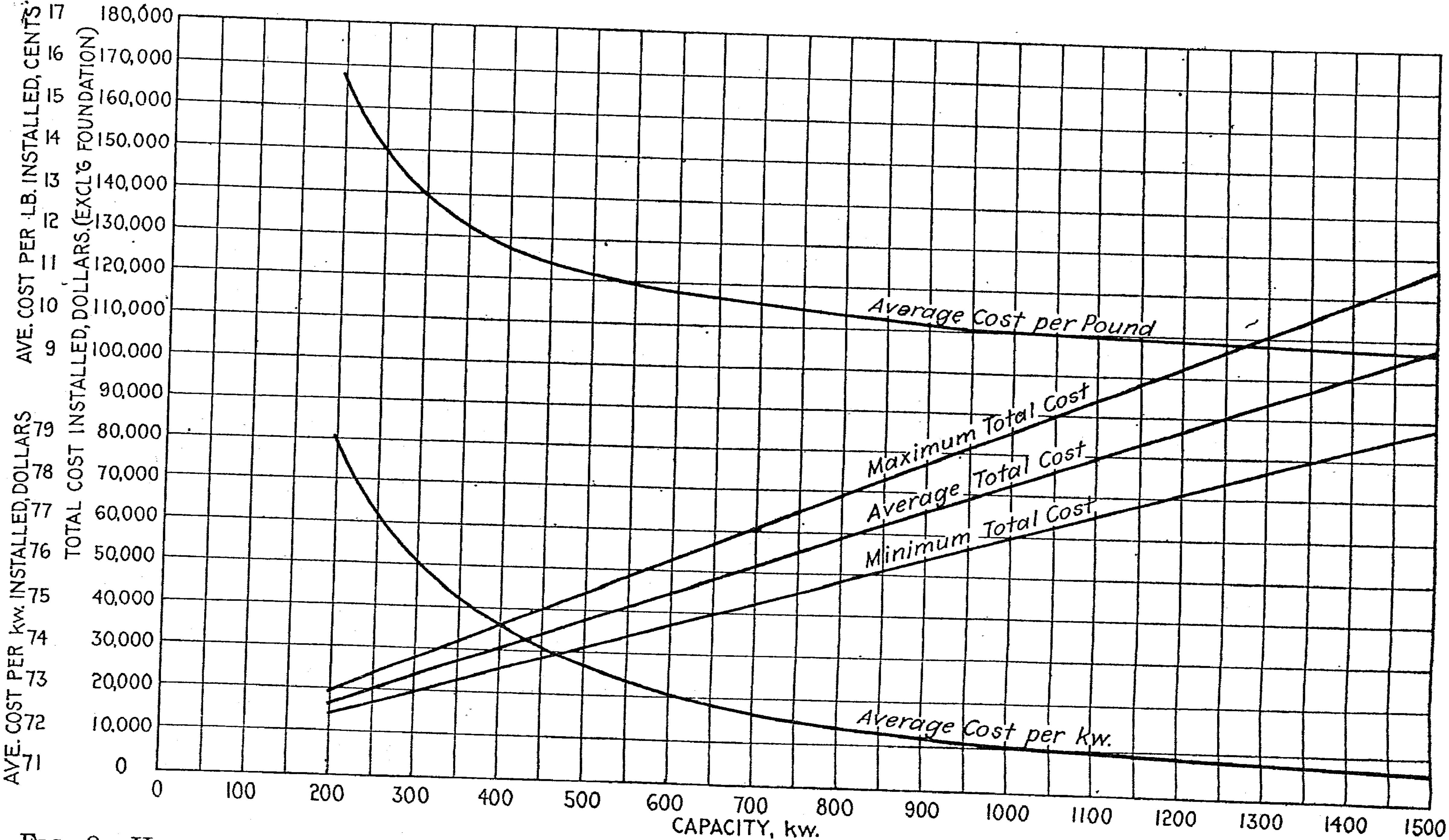

FIG. 8—HORIZONTAL TYPE (AMERICAN MANUFACTURE) PRODUCER GAS AND NATURAL GAS ENGINES, 4-CYCLE, TANDEM AND TWIN TANDEM, DIRECTLY CONNECTED TO 60-CYCLE GENERATORS FROM 200 TO 2000 KW. CAPACITY AT 80 PER CENT POWER FACTOR

lower cost, many manufacturers have launched out to build them.

There are approximately 300 installations of medium- and heavy-duty oil engines, aggregating over 75,000 h.p., in operation in the United States.

On account of the very high cost of natural oils in countries that do not have an oil production of their own, the use of tar oil with a small addition of ignition oil in the Diesel engine is rapidly finding favor. Some oil engines operate satisfactorily on any fuel and especially the crude oils produced in this country, while others are limited to certain qualities. The recognition that coal is too valuable a fuel to be wasted in our present-day furnaces, is spreading, and much interest is being taken in the by-product coke oven and by-product gas producer plants, in hope that the production of tar oil, an artificial product, will aid to check the advance in price of natural liquid fuels. In this country the condition is different on account of the supply of rich natural oils, such as the light grades of crude oil produced in the eastern fields, as well as the heaviest grades produced by the California, Texas, Oklahoma and Mexican fields, which are largely asphalt base.

Capacity. Similar to the gas engine, the oil engine does not possess an inherent overload capacity in the same sense that the steam turbine does, hence, whatever overload is required must be provided by the manufacturer.

The oil engine is restricted in size for the same reasons given in the case of gas engines. The largest Diesel engine operating in this country is a 450 brake horse power double-unit vertical four-cycle three-cylinder type, whereas in Europe they have been built as large as 2500 brake horse power. There has recently been built in Germany a 2000 brake horse power horizontal double-acting, four-cycle, twin-tandem Diesel engine operating with tar oil, which promises interesting results.

Efficiency. The thermal efficiency of the oil engine varies slightly with the capacity. Unlike the gas engine, the thermal efficiency does not increase with the load beyond the capacity of the engine.

Figures of efficiency have been given at different times that cannot be substantiated. With oil having 19,000 B.t.u.'s (4788 large calories) per lb. (0.4534 kg.), the thermal efficiency and fuel consumption that may be expected at different percentages of normal full load rating, no allowance being made for auxiliaries, are shown in Fig. 9.

At full load the fuel consumption is 0.64 lb. (0.29 kg.) per kw-hr. or 0.45 lb. (0.204 kg.) per brake horse power, and the thermal efficiency 28.2 per cent per kw-hr., or 29.8 per cent per brake horse power.

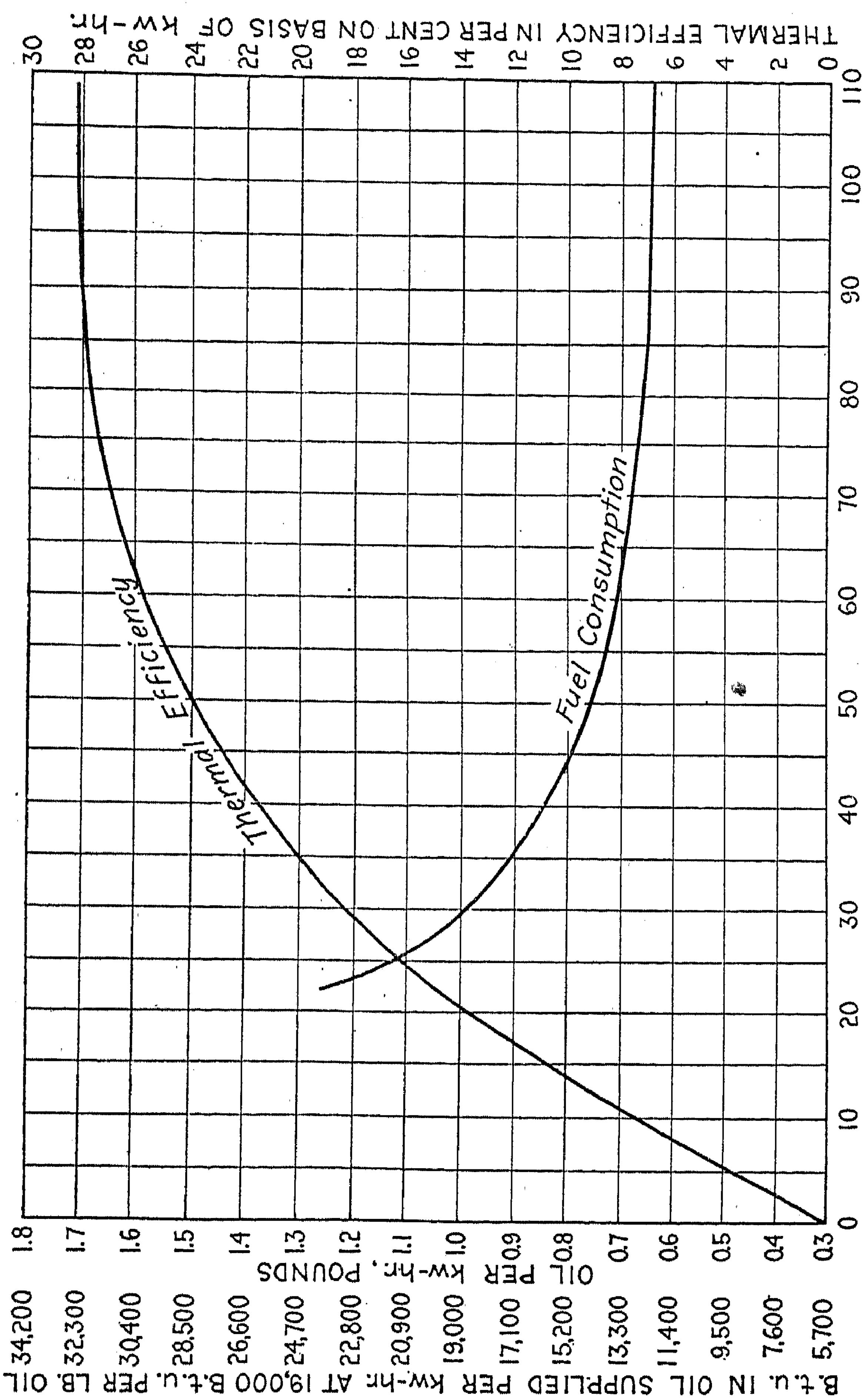

FIG. 9—VERTICAL DIESEL ENGINE, 4-CYCLE, 3 AND 6 CYLINDERS, DIRECTLY CONNECTED TO 60-CYCLE GENERATORS (AUXILIARIES NOT ALLOWED FOR)

The fuel consumption of the best oil engines to-day, made in large sizes, varies from 0.40 to 0.50 lb. per brake horse power, the highest fuel economy being obtained by the four-cycle type.

Weight. The Diesel engine is inherently massive for the same reason as the gas engine, namely, high temperatures and pressures, consequently the weight, including engine and generator, per kilowatt capacity, increases with the size, as shown in Fig. 10.

It will be seen that the increase in weight from 40 to 160 kw. capacity is very rapid, while with sizes larger than 160 kw. it is not so pronounced.

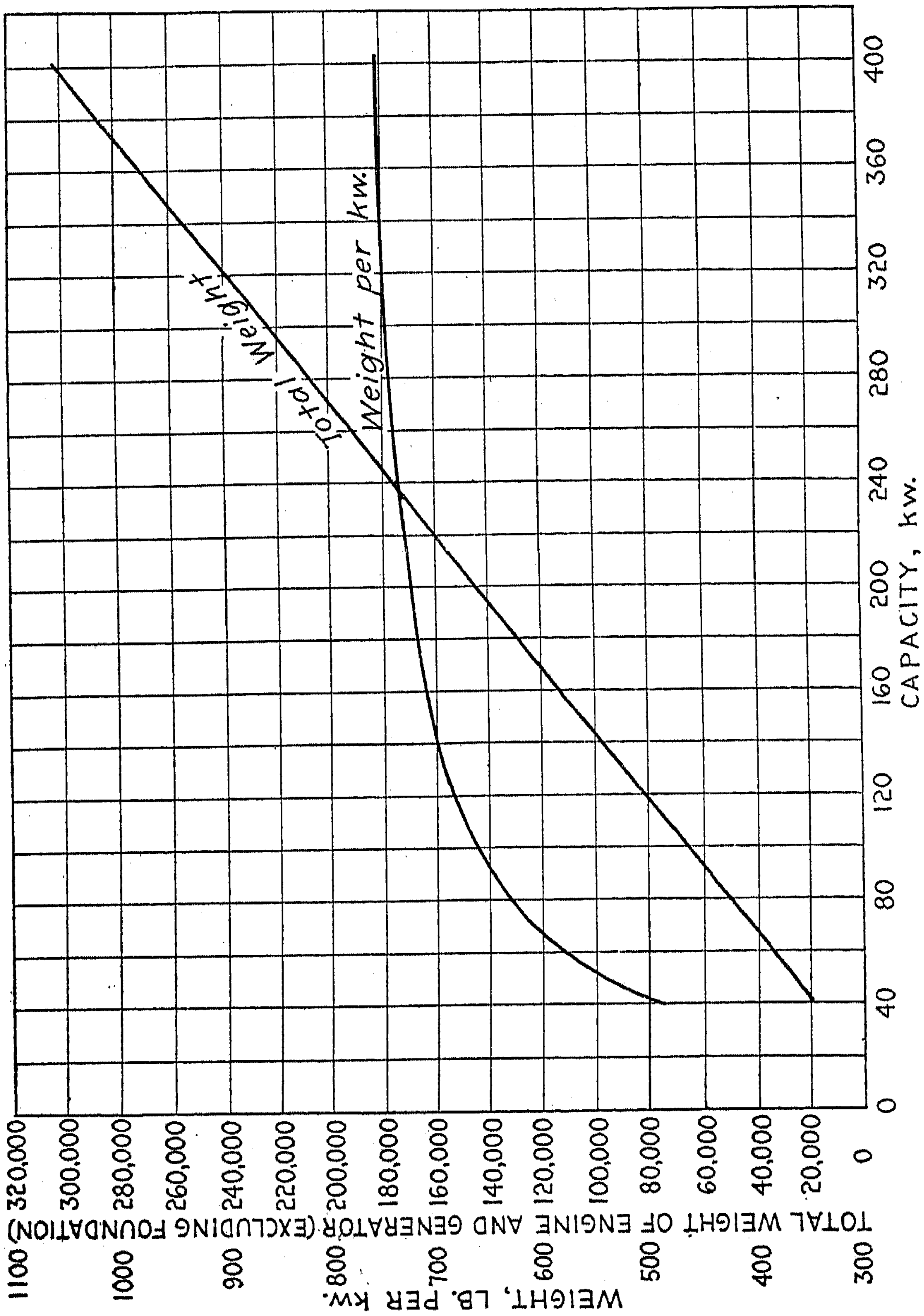

Fig. 10—Vertical Diesel Engine (American Manufacture) 4-Cycle, 3 and 6 Cylinders, Directly Connected to 60-Cycle Generator, 40 to 400 kw. Capacity.

High-compression Diesel-cycle crude-oil engines of the two- and four-cycle, single- and twin-cylinder, horizontal type, using a heavy grade of crude oil, are now being manufactured in America as large as 500 h.p. capacity, some companies standing ready to construct units of 800 h. p. capacity if required. Fig. 12 shows the average total weight and weight per kilowatt capacity for these machines.

Cost. There have been so few oil engines driving generators of any appreciable size installed in this country that it is a difficult matter to tabulate any costs for comparative purposes with other prime movers. The most reliable figures available for the Diesel engine average approximately $95 per kilowatt installed, including engine and generator complete, but not the foundations, within 600 miles of factory. Fig. 11 gives the average total cost per kilowatt for all sizes at $95 per kw., also the cost per pound, which decreases but slightly for machines above 160 kw. capacity.

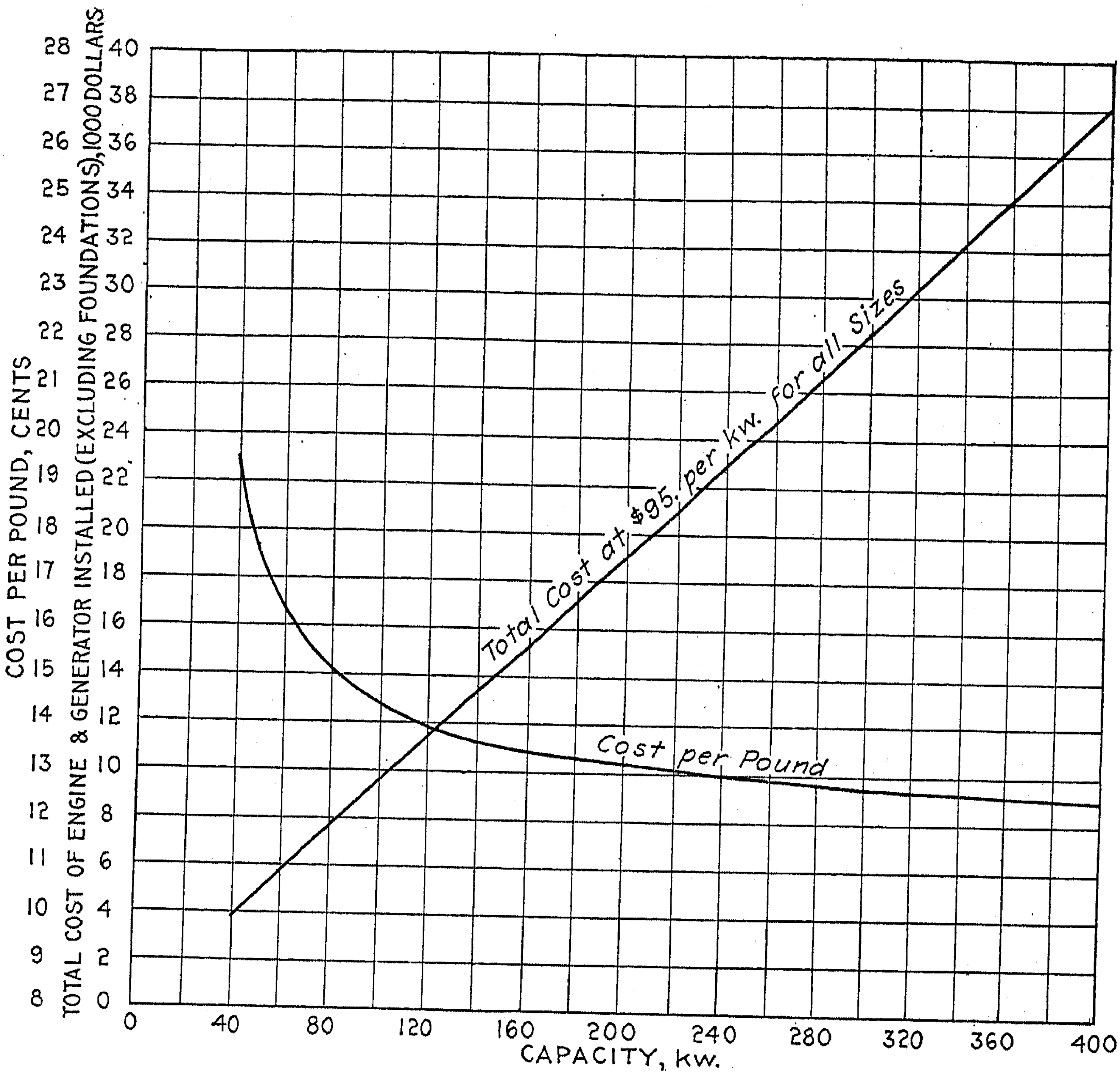

FIG. 11—VERTICAL DIESEL ENGINE (AMERICAN MANUFACTURE) 4-CYCLE, 3 AND 6 CYLINDERS, DIRECTLY CONNECTED TO 60-CYCLE GENERATOR, 40 TO 400 KW. CAPACITY

Important improvements in the construction of the vertical type Diesel engine are being made in this country, as well as in Europe, which will probably reduce the weight and consequently the unit cost.

The average total cost, average cost per kilowatt and average cost per pound of two- and four-cycle, horizontal, crude-oil engines, American manufacture, including engine and generator, are shown in Fig. 13, corresponding to the weights given in Fig. 12.

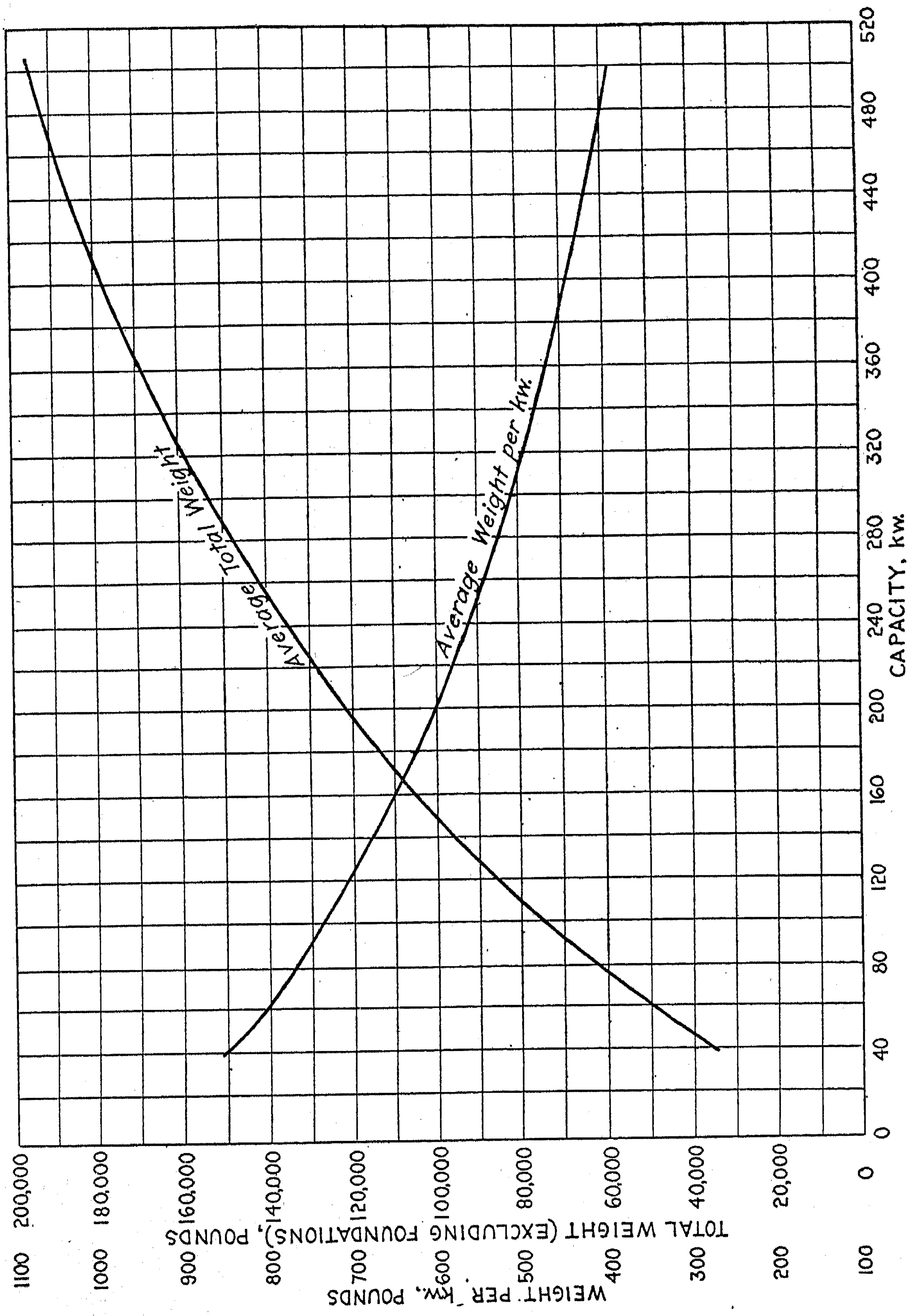

FIG. 12.—HORIZONTAL TYPE (AMERICAN MANUFACTURE) CRUDE OIL ENGINE, DIRECTLY CONNECTED TO 60-CYCLE GENERATORS FROM 40 TO 500 KW. CAPACITY AT 80 PER CENT POWER FACTOR

There is considerable variation in the weights and costs of the horizontal type oil engines of the different manufacturers, and for this reason the average curve is given instead of the maximum and minimum. The weights and costs are fairly consistent for the single cylinders of all sizes, the greatest difference being with the twin- and four-cylinder types. These curves hold fairly well for the so-called semi-Diesel horizontal type.

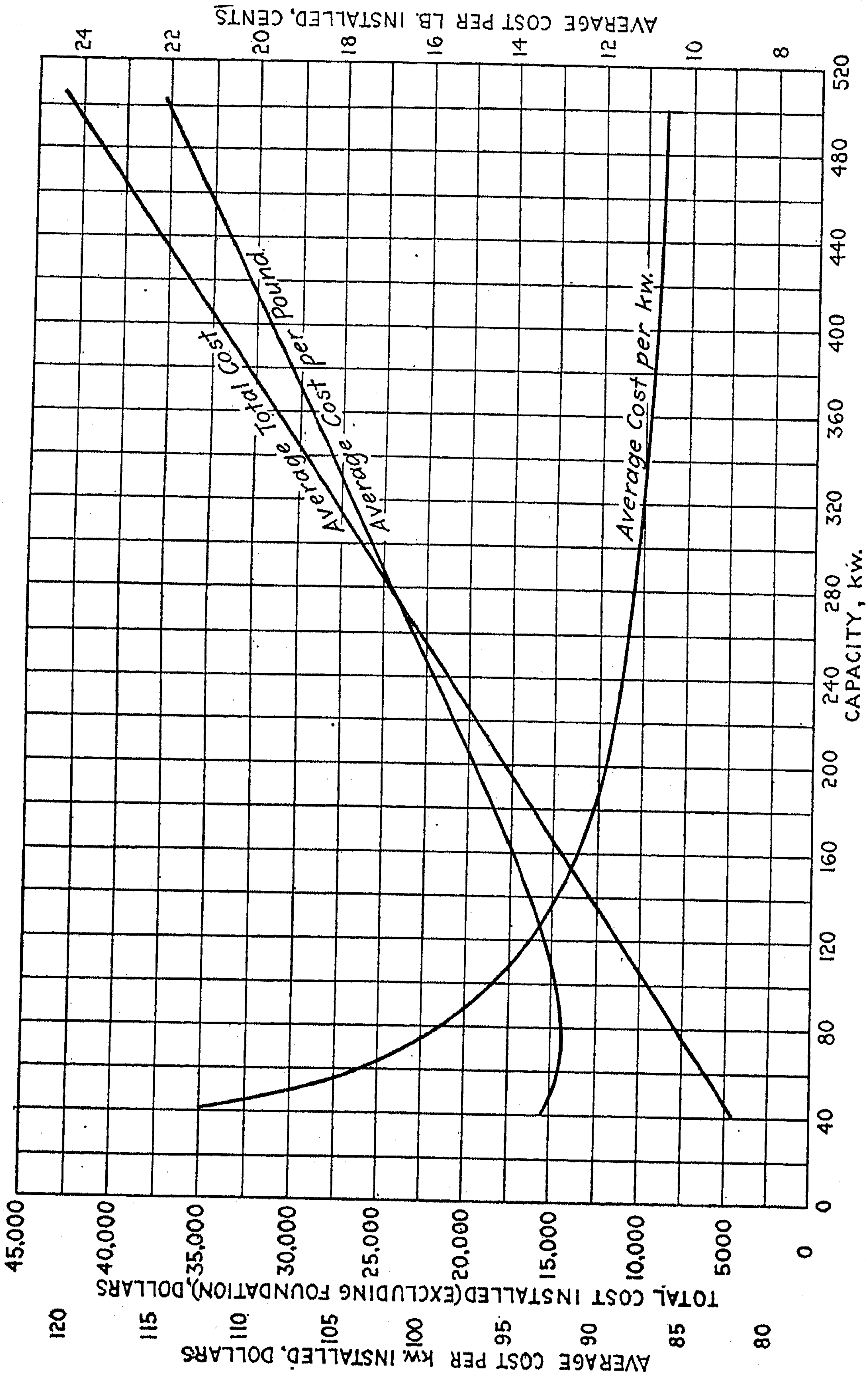

Fig. 13.—Horizontal Type (American Manufacture) Crude Oil Engine, Directly Connected to 60-Cycle Generators from 40 to 500 kw. Capacity at 80 per cent Power Factor

HYDRAULIC TURBINES

development of hydroelectric power installations has l new demands on the designers and manufacturers of lic turbines for betterments in efficiency, power, speed, h and size of turbine runners.

arly hydraulic installations, efficiency was frequently of mportance, but as the demands for power increased, and pacity of sources of water supply became overtaxed, high cy became of importance.

he case of modern hydroelectric developments, there are urces of supply so great that the efficiency of the installed nery is not of the highest importance. The demand on e designers and manufacturers for increased efficiency en met by better design, better construction, and better and as a result, the efficiency of turbines has been so in- d that in the case of at least four different manufacturers, ncies of 90 per cent or over have recently been obtained hydraulic testing flume at Holyoke under the best condi- of gate, speed and head; and high efficiencies can now be ained through considerable variations both of head and , as will be seen by reference to Fig. 14.

ent tests at Holyoke on a high specific speed 28-in. (71-cm.) al Francis type turbine, the results of which are shown . 15, represent the best that is being accomplished at the nt time.

will be seen that the efficiency remains fairly constant gh a considerable variation in power. The efficiency at r cent gate opening is 91.5 per cent and at full gate it ed to 84 per cent.

direct connection to comparatively high-speed electrical inery, both capacity and speed, together with high effi- y, are common demands. A comparison of the power ity of various types of wheels can best be made on the basis power of the unit wheels of the various types under the ead. This unit power is represented by the equation

$$\mathcal{P} = \frac{P}{D^2\, h^{3/2}}$$

s the unit power of the unit wheel of the type considered r unit head,

s the power (h.p.) of any wheel under the head h,

is the diameter in inches of the wheel considered,

s the head in feet under which the power (P) is developed.

In each case the best conditions of speed and efficiency are assumed to obtain.

In the original Boyden-Fourneyron turbine of 1849, the value of $\mathcal{P}$ was equal to........................ 0.00032
This was increased by Swain in 1855 to.... 0.0008
By McCormick in 1860 to................ 0.0014
By a number of recent designers to values from 0.002 to 0.0024
And has been extended to................ 0.00388
in a recent design, without a reduction in efficiency below 87 per cent, an enormous increase in power which is quite worthy of note.

Capacity and speed are both often highly desirable for electric machinery if both can be extended without too great a sacrifice in efficiency. The combined capacity and speed may be compared by the speed-power coefficients of the various types (see page 1409, Vol. XXXI, TRANSACTIONS A. I. E. E.), which may be termed the "specific power" of the wheel, and which is represented by the equation

$$\mathcal{P}_s = \frac{n^2 P}{h^{5/2}}$$

in which n = the revolutions per minute of the wheel under the head h and with the horse power P. The speed-power coefficient $\mathcal{P}_s$ is the square of the coefficient of unity speed.

The value $\mathcal{P}_s = 10{,}000$ had barely been reached in 1910, but during the present year a designer has succeeded in increasing the value to $\mathcal{P}_s = 11{,}800$.

Such wheels are frequently of high value for low-head and high-speed conditions, but cannot maintain such high efficiencies under great ranges of head and loads as can be maintained with wheels of lower "specific power," such as are shown in Fig. 14.

Among the more recent improvements in the construction of hydraulic reaction turbine runners may be mentioned the construction of high-capacity runners of cast steel in single castings, thus giving great strength with large capacity under high heads to which such turbines could not previously be applied.

The recent successful construction of the large single reaction turbines for the Keokuk hydroelectric plant is also worthy of note. These turbines are 16 ft. 2 in. (4.875 m.) in diameter and will operate at 57.7 revolutions per minute under a 32-ft. (9.75-m.) head. The runners weigh 73 tons each and develop 10,000 h.p. While greater power has previously been developed by single wheels under high heads, these wheels are remarkable for the amount of power developed under the low head utilized.

Since 1911, the trend has been toward the adoption of the single-runner, vertical-shaft turbine for low and medium heads. This change in type of unit is due to the recent progress in the design and development of high-capacity runners, also the improvement in thrust bearings.

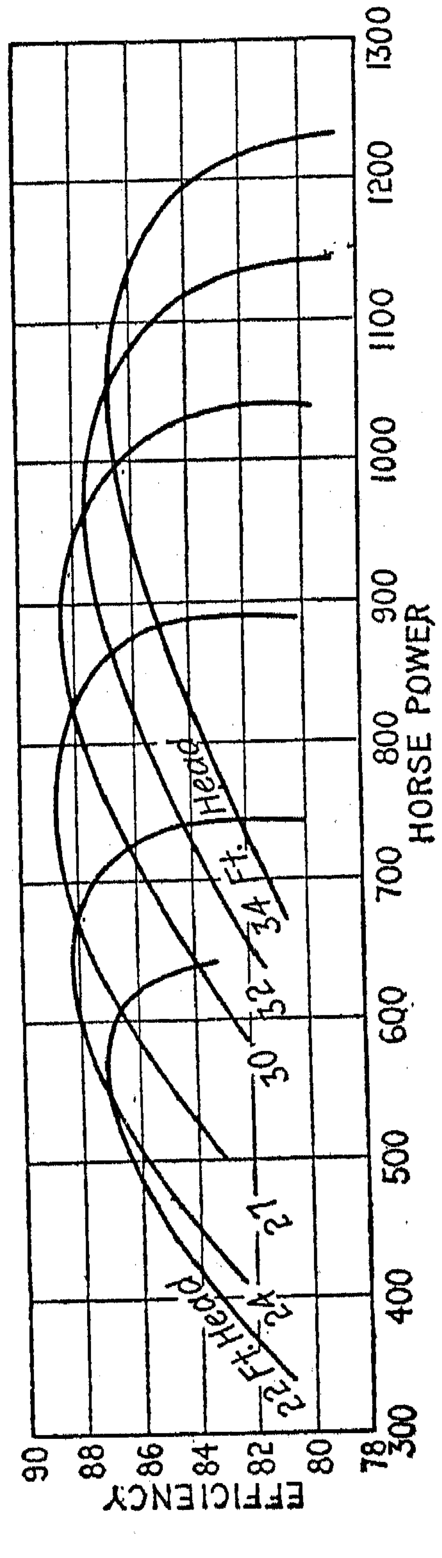

FIG. 14—WATERWHEELS

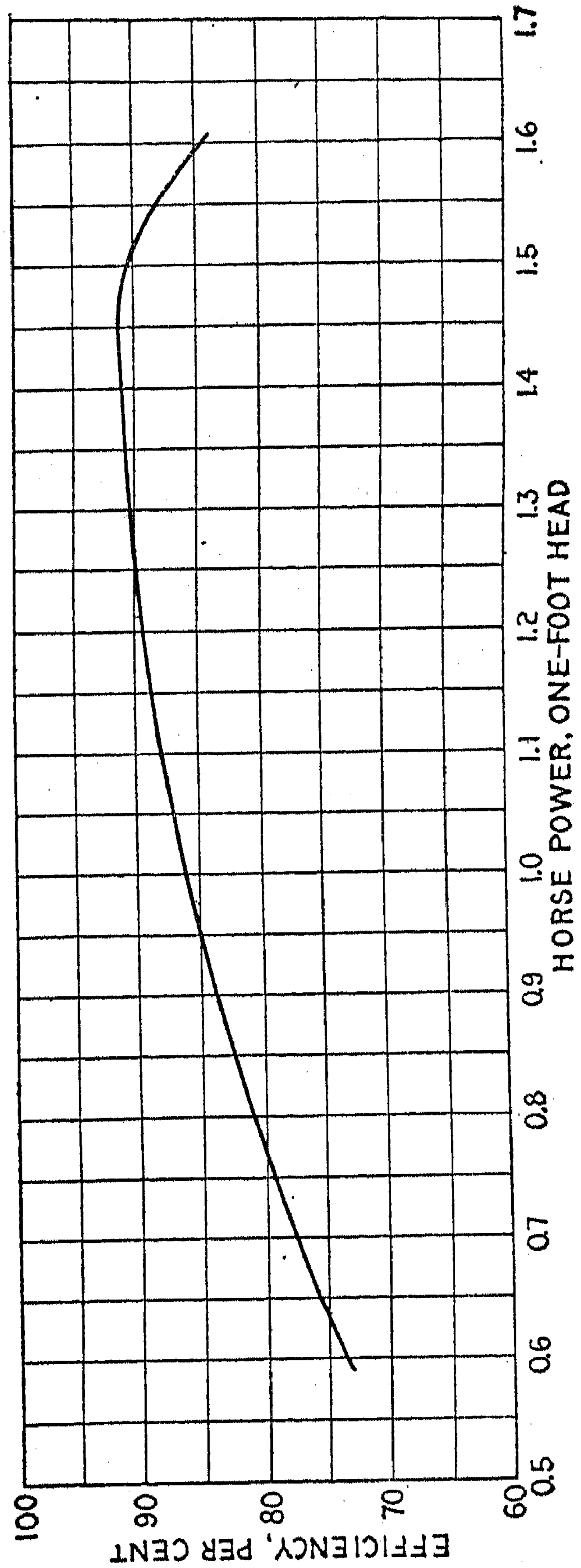

FIG. 15—EFFICIENCY CURVE OF HIGH-SPEED VERTICEL FRANCIS TYPE TURBINE

Prior to this time, the majority of turbines for low and medium heads were either of the vertical-shaft, multi-runner type, or of the horizontal-shaft, multi-runner type.

Weight and Cost. The weights and costs of hydraulic prime movers are not strictly comparable with the steam turbine, gas and oil engines, for in the case of the thermodynamic prime movers, the conditions are more or less fixed and the costs relatively uniform, whereas with the water turbines they vary between fairly wide limits, depending upon the conditions under which they are to be operated. The head, kind of flume, open or closed, setting vertical or horizontal, single or multiple, material in runner, which may be made of cast iron, cast steel, gun metal, bronze, etc., depending upon the service conditions, are some of the factors that cause the price and weight to vary materially. With a given head, the greater the power of the turbine the less the unit cost. With a given head and power, the higher the speed the less the unit cost. On the other hand, with a given power, the lower the head the greater the unit cost. For illustration, a water turbine developing 50 h.p. under a 30-ft. (9.14-m.) head, and costing $18 per horse power, will develop approximately 300 h.p. under a 100-ft. (30.4-m.) head, and will cost only $3 per horse power, assuming other conditions equal. In reality the cost of the turbine under the 100-ft. (9.14 m.) head would be slightly higher than $3, as the construction would naturally be more expensive.

In general it can be said that the cost of hydraulic turbines and generators larger than 200 kw. capacity will vary from $30 to $10 per kilowatt installed, exclusive of foundations.

With the broader field now covered by turbine design and construction, the necessity for careful selection has become most important, and the hydraulic engineer can at the present time secure hydraulic turbines of the best character and design only by careful attention to the intelligent analysis of turbine possibilities, and the selection of wheels suited to the particular conditions of head and load under which such turbines are to operate.

FINANCE AND ECONOMICS

Investment and Fuel Costs.

a. Heat Engines. In comparing the various types of prime movers, conclusions are often reached, largely from a study of the cost of fuel, without any reference whatever to the total cost of power and the relative investment costs. As it is not within the scope of this paper to include operating and maintenance costs for the entire plant, investment costs of the units and fuel costs are shown plotted in conjunction with the percentage of normal full-load rating in Figs. 16 and 17, for making an economic study of the various types of prime movers.

The impression that gas and oil power invariably imply a lower cost of generation is constantly losing ground through the critical analysis of the elements of power costs. Fuel is only a fraction of the total cost of power, and there are conditions where it is overbalanced by other costs.

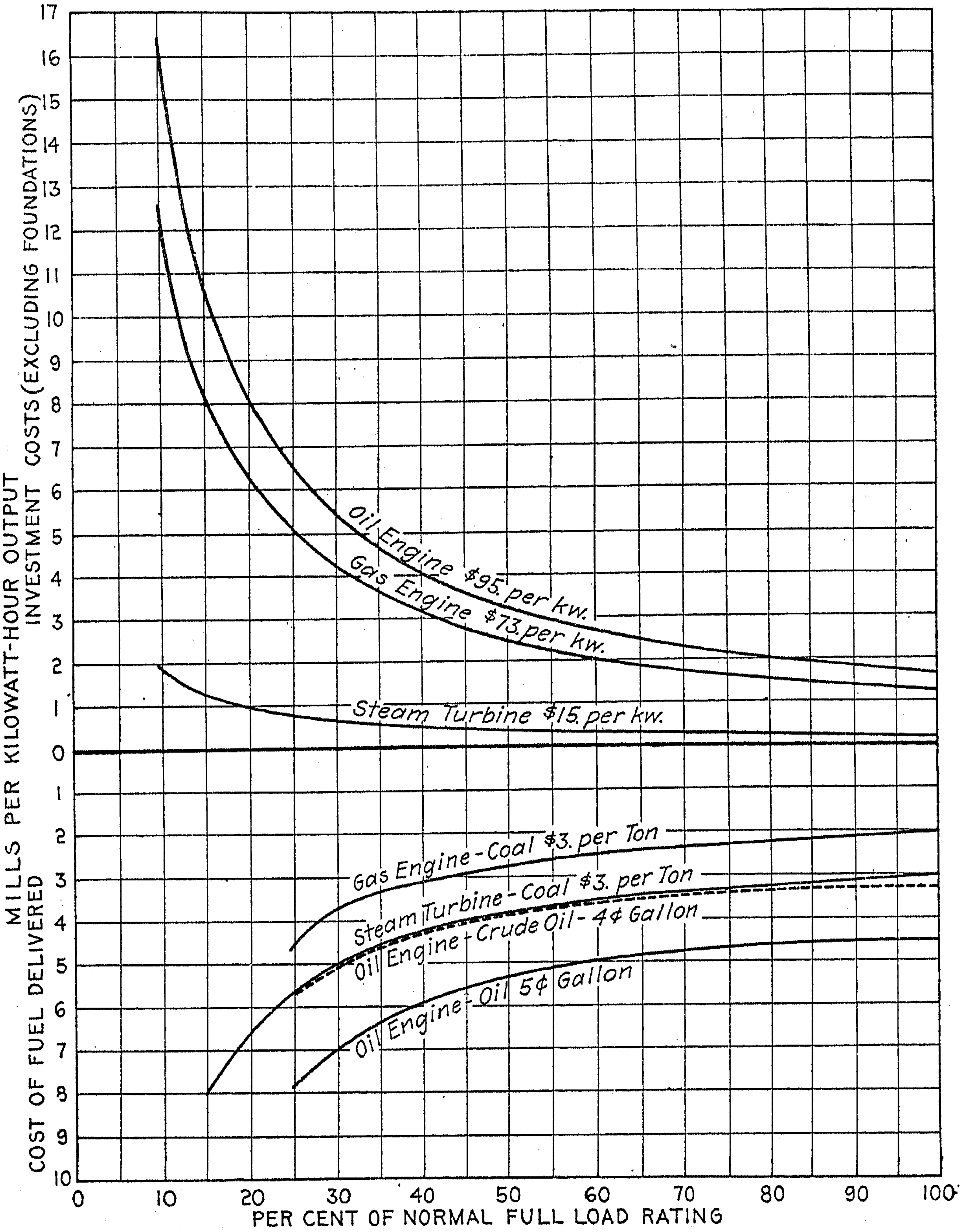

FIG. 16—RELATIVE INVESTMENT AND FUEL COSTS OF A 750-KW. STEAM TURBINE, GAS ENGINE, AND OIL ENGINE, INCLUDING DIRECT-CONNECTED 60-CYCLE-GENERATOR, OPERATING AT DIFFERENT PERCENTAGES OF NORMAL FULL LOAD

Claims have been repeatedly made that steam turbines use two and one-half times the amount of fuel consumed by gas engines, but these statements are without foundation. Before any fair comparison can be made of fuel consumptions, records should be kept over a reasonably long period and the coal reduced to a common basis as to B.t.u. per pound and the percentage lost in refuse.

The curves plotted in Fig. 16 are for small machines of 750-kw. capacity—the steam turbine a single unit costing $15 per kilowatt, the gas engine a single unit costing $73 per kilowatt, and the oil or Diesel engine a double unit costing $95 per kilowatt. These prices are for the prime mover and generator delivered and erected (exclusive of foundations) within 600 miles of the factory.

The investment costs are taken at 11 per cent for the steam turbine and 15 per cent for the gas and oil engines. In investment costs are included interest, taxes, insurance and amortization fund, that is, an arbitrary percentage that should be set aside and the percentage corrected, if necessary periodically, so that when the apparatus is condemned on account of obsolescence or inadequacy, there will be a fund which will meet the expense (see A. I. E. E. TRANS., 1913, Vol. XXXII, p. 1619.)

Coal for both the steam turbine and gas engine is taken at $3 per ton (1016 kg.) having 14,500 B.t.u. (3654 large calories) per lb. (0.4534 kg.) delivered alongside the dock. On account of the wide fluctuation in price of the same oil at the same locality, two figures are used, namely, four and five cents per gallon (3.785 litres). All auxiliary costs are included, but stand-by costs are not, as these vary widely with the conditions of operation.

Adding the investment and fuel costs for any percentage of normal full load rating, the steam turbine will be found to be slightly less than the gas, and considerably less than the oil engine. Even with stand-by losses allowed, the turbine will still have the advantage over the gas engine for loads below 80 per cent full load rating.

The investment costs are computed on the normal full-load rating, and if advantage is taken of the overload capacity of the turbine, which is approximately 25 per cent for 24 hours, the cost per kilowatt-hour during such periods of maximum capacity will be less than shown by the curve. This does not apply to gas and oil engines, as what little overload capacity may be allowed in these machines is for a short period of two hours or even less.

Another set of curves is plotted in Fig. 17, showing a single turbine unit of 20,000-kw. capacity, costing $7.50 per kilowatt, ten 2000-kw. gas-engine units costing $65 per kilowatt, and forty 500-kw. oil-engine units at $85 per kilowatt. In a plant of this capacity the gas and oil engines are practically out of the running, with these fuel costs.

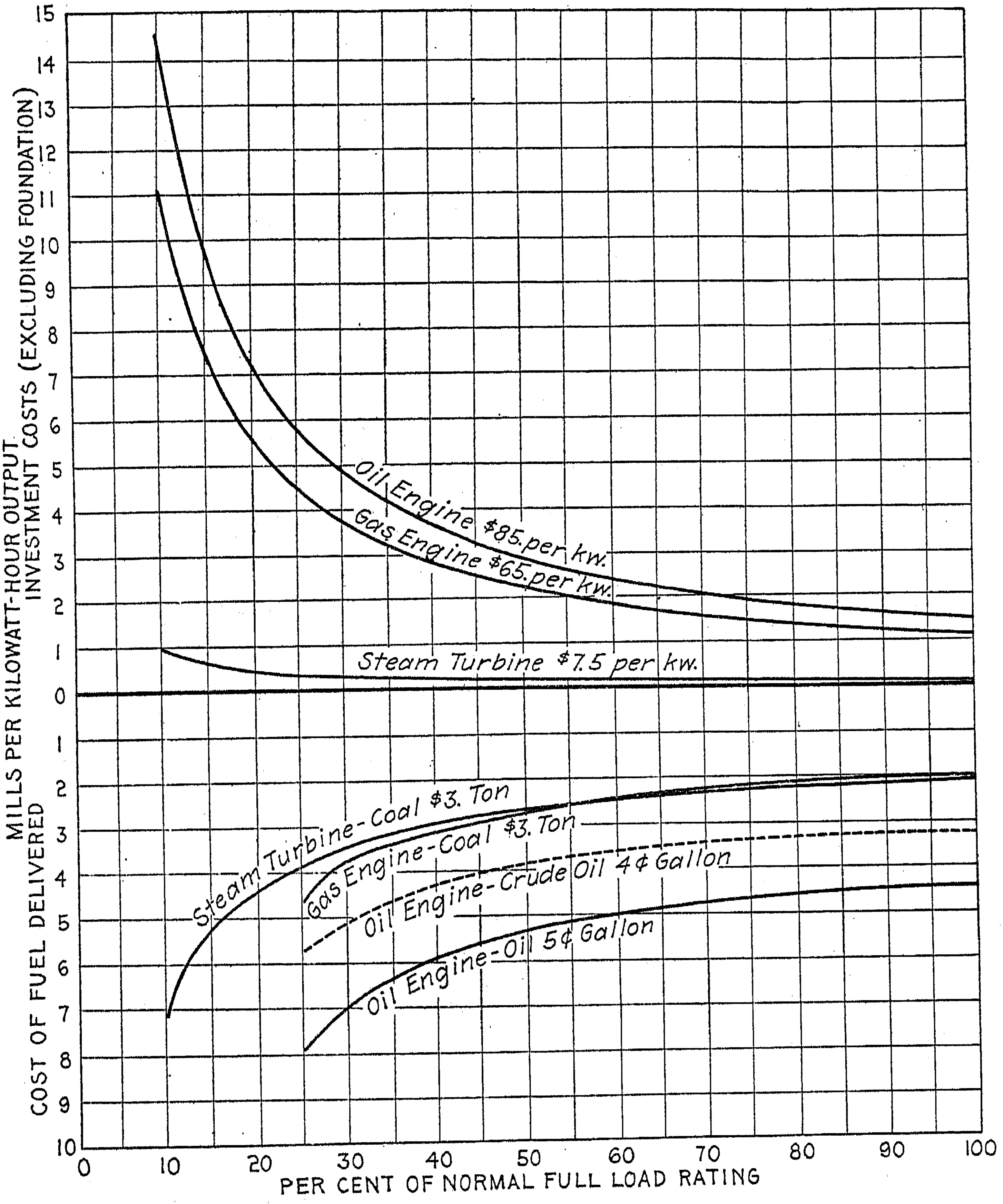

FIG. 17—RELATIVE INVESTMENT AND FUEL COSTS OF PRIME MOVERS DIRECTLY CONNECTED TO 60-CYCLE GENERATORS OF 20,000 KW. CAPACITY, OPERATING AT DIFFERENT LOADS

Steam Turbine—1 unit 20,000-kw. normal rating.
Gas Engine—10 units 2000-kw. " "
Oil Engine—40 units 500-kw. " "

In computing the cost of fuel the coal was put on the same basis, namely, 10,825,000 B.t.u. (2,727,868 large calories) per dollar, whereas the oil at 4 cents per gallon is equivalent to

3,718,000 B.t.u. (936,925 large calories) per dollar. This may look as though the steam turbine and gas engine were being favored, but in comparing prime movers as they stand to-day they must be considered in connection with the prevailing cost of fuel. While it is possible to get a cheaper coal than $3 per ton (1016 kg.) with 14,500 B.t.u. (3654 large calories) per lb. (0.4534 kg.), it is a question whether many more B.t.u's. (large calories) of natural oil per dollar can be obtained, except in a few localities.

If natural instead of producer gas is considered, it would cost about 10 cents per 1000 cu. ft. (28.317 cu.m.), which is a reasonable figure, as the price varies from 5 to 25 cents per cubic foot, depending upon the location of the well.

At 40 per cent of normal full-load rating, the investment cost for the gas engine is approximately 90 per cent of the fuel cost and for the oil engine using oil at four cents per gallon (3.785 liters) it is about 80 per cent, whereas with the steam turbine it is only 7 per cent.

If we assume for illustration, that in a small plant it is possible to obtain a horizontal semi-Diesel installation, including engine and generator delivered and erected, excluding foundations, for $73 per kilowatt, and that oil can be purchased for 3.5 cents per gallon (3.785 liters) delivered, it will be seen from Fig. 16 that while the cost of fuel will be slightly in favor of the oil engine, the sum of the ordinates above and below the axis for any percentage of load will be in favor of the steam turbine. With larger installations it will be seen by referring to Fig. 17 that the turbine has decidedly the advantage.

All these illustrations are on the basis of the normal full-load rating of the plant; however, if reserve capacity is allowed for to insure continuity of service, the investment costs for the gas and oil engines will be proportionately higher than for the steam turbine.

From a study of these curves it will be seen that the ratio of cost of steam to gas and oil units is decidedly in favor of the former so that gas and oil power becomes severely handicapped in large work owing to the proportionately greater investment burden. And, unless the price of coal rises materially above the present value, the gas and oil engines will find limited application in stations of any appreciable size, except under very favorable circumstances, where natural gas, by-product gas or some artificial fuel oil can be secured at low prices. If maintenance cost and the additional investment cost required to assure reliability or continuity of service are included, the steam turbine will stand out more prominently.

b. Hydraulic Turbines. The redeeming feature of the water turbine, which gives it an advantage over other prime movers, is the absence of fuel. As a result, the operating expenses are practically the same whether the plant is working 10 or 24 hours per day. On the other hand, the investment cost is influenced by the load factor, but it is doubtful in any case whether the cost of water turbine and generator will exceed twice that of the steam turbine and generator on the basis of 11 per cent. When the investments costs include an adequate supply of auxiliary capacity to supplement the deficiency in stream flow, the difference between the investment costs of prime movers plus the fuel costs, at any percentage of normal full load rating, will not be so marked, as the investment costs of the units of the hydroelectric plant will not only be much higher than a straight steam plant, but in addition, there will be fuel costs for the reserve units. In fact, with the same class of service, and the reliability charge in the form of duplication of units or steam reserve, the straight steam turbine units will in many cases be more economical.

In low-priced fuel districts the hydraulic turbine is only a competitor of the steam turbine where the development costs are moderate and the load factor reasonably high.

More attention is now being given to the important relation between the efficiency and durability of the water turbine than has been in the past. It is the opinion of some engineers that the most efficient turbine, if operated too constantly at low gate opening is likely to show some pitting if the head is high, and they recommend that turbines of high specific speed be kept as closely loaded as possible to the point of maximum efficiency, while with turbines of lower specific speed it is not necessary to operate within such close limits.

General. The proportion of the total investment cost of a 20,000-kw. plant represented by the prime mover and generator for the various types of units, is approximately as follows:

Prime mover	Total investment cost per kw.	Cost of prime mover and generator per kw.	Percentage of total investment
Steam turbine......	65.00	7.50	11.5
Gas engine......... (Producer gas)	140.00	65.00	46.5
Oil engine.........	120.00	85.00	71
Hydraulic turbine ..	125.00	12.00	9.6

The unit costs are the average values obtained from the cost curves given above, while the total costs were estimated and are only approximate, especially in the case of the oil engine, as it is impossible to obtain reliable data for this type of installation.

Considering the different types of prime movers in connection with the total investment cost of the plant, it is evident from a study of curves similar to Figs. 16 and 17, developed on a load factor and total cost basis, that with a very poor load factor the all-important point is to keep down the fixed charges, as they are of vastly greater importance than any possible gain in efficiency due to a better type of prime mover of the same class. This is true of any plant, and the curves will show the futility of attempting to carry peak loads by means of water turbines, gas and oil engines or any prime mover that necessitates a large investment per kilowatt.

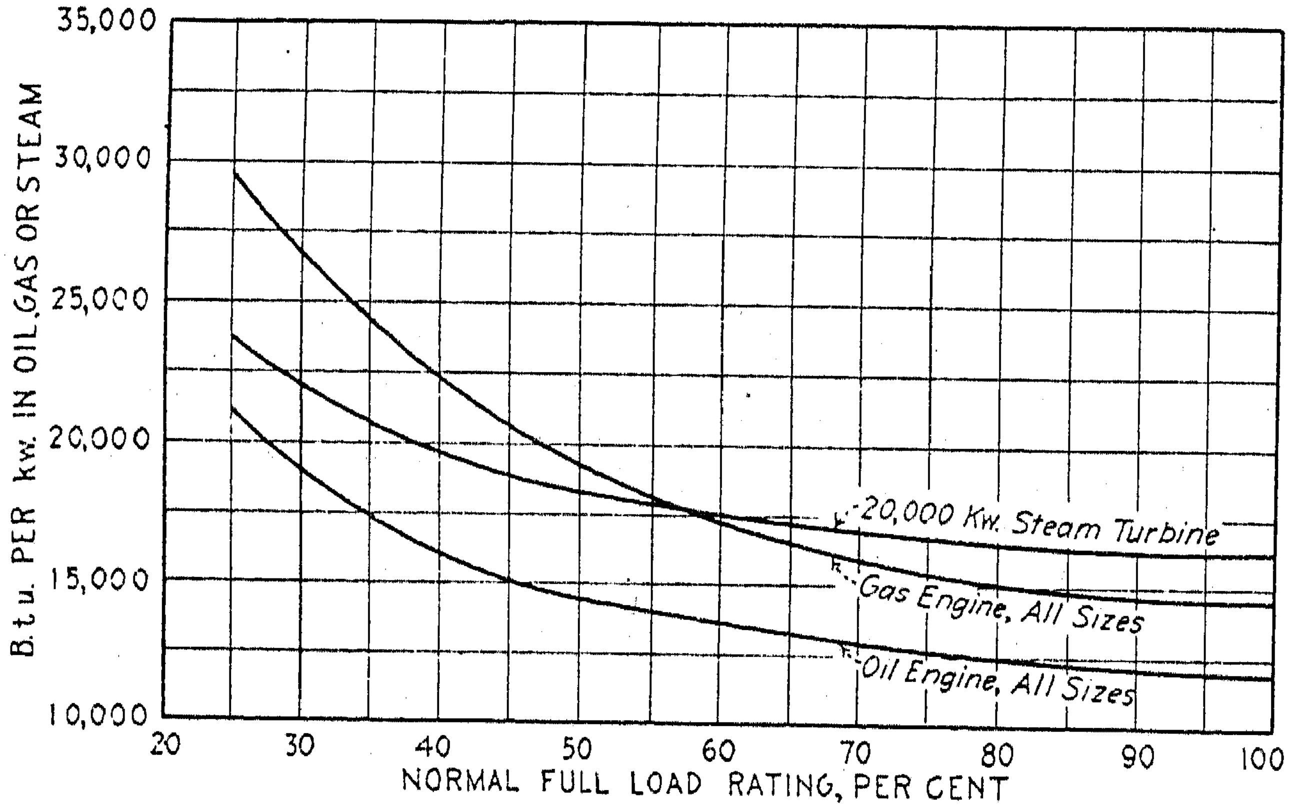

FIG. 18—RATES OF HEAT CONSUMPTION PER KW. AT DIFFERENT PERCENTAGES OF NORMAL FULL-LOAD RATING

Efficiency and Heat Consumption. Figs. 18 and 19 are presented to show conservative thermal efficiencies and heat consumptions in B.t.u. per kilowatt-hour at different percentages of normal full-load rating, for two sizes of steam turbines and for all sizes of gas and oil engines, reckoned on the heat in the steam, gas or oil delivered to the throttle valve, and do not include boiler or producer losses or auxiliaries.

It is evident that as the larger sizes are approached the inequality between the steam turbine and gas engine steadily vanishes until finally the former exceeds the latter. It is interesting to note that at normal full-load rating the thermal efficiency of the 20,000-kw. steam turbine, which is based on 175 lb. steam pressure and 100 deg. superheat, is 24.2 per cent, and the producer or natural gas engine 23.8 per cent, both referred to kilowatt-hour output. Referring to Fig. 2, it will be seen that the average thermal efficiency of steam turbines larger than 14,000 kw. is between 24 and 25 per cent, and the maximum value for very large machines is a little below 25.5 per cent.

An important feature of the steam turbine, and especially the oil engine, is that the efficiency does not materially decrease until the load falls below 25 per cent of the normal rating, whereas the gas engine changes rapidly.

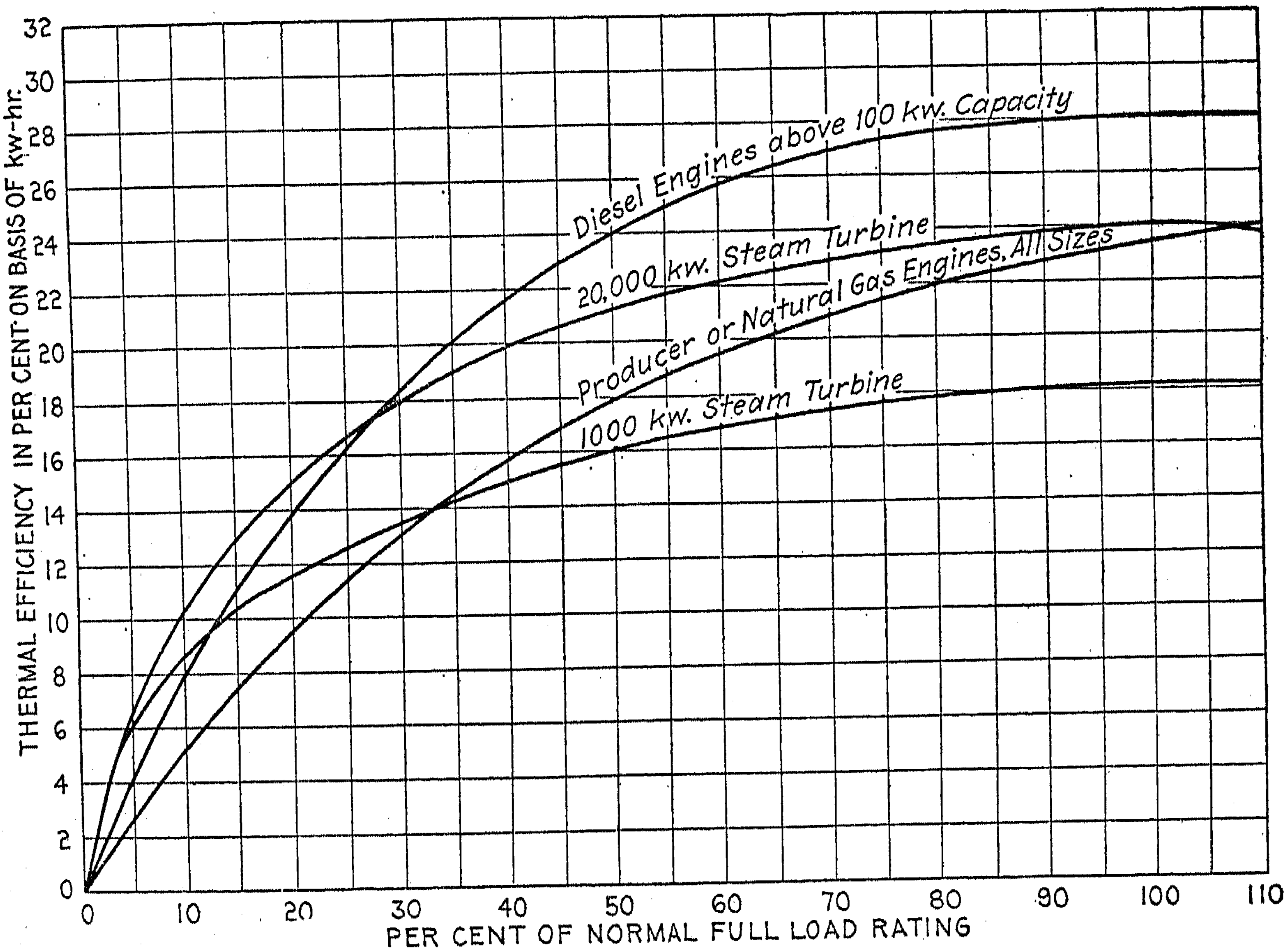

FIG. 19—THERMAL EFFICIENCY OF PRIME MOVERS (AUXILIARIES NOT ALLOWED FOR)

In small plants with a low load factor, efficiency may be a secondary matter compared with investment cost, and the cost of maintenance and reliability.

Maintenance and Reliability. On account of the high mechanical stresses inherent in the gas and oil engines, and heavy reciprocating masses, there is necessarily greater maintenance and repair cost, also a lower reliability of service and a higher class of attendance than for either the steam or water turbine units. The reliability of the gas and oil units has not been sufficiently established to warrant their adoption for reasonably large power stations operating 24 hours daily, without the plant being over-burdened with some type of reserve and consequently excessive investment costs.

SPACE ECONOMY

This factor affects the investment cost of power, and is especially of very great importance for plants of any appreciable size in large cities or where property is expensive. For different sizes of the various types of prime movers the number of kilowatts per square foot of floor space occupied, is from 10 to 15 for horizontal steam turbines, and from 0.5 to 0.8 kilowatt for gas and oil engines. Where a number of gas and oil engines are installed and the passage-ways included, the contrast will be still greater.

SUMMARY

Perhaps the most remarkable fact brought out in this report is shown in Fig. 19, where we find that the large steam turbine has now passed the gas engine in thermal efficiency and the only prime mover surpassing it is the Diesel type of oil engine. The oil engine reaches a maximum efficiency of about 28 per cent as compared to about 24 per cent for the latest type of 20,000-kw. high-vacuum steam turbine, and there is every prospect that at least 26 per cent will be realized before the end of the current year.

The present limit in size of the Diesel type engine seems to be about 1800 kw., so that for plants in excess of 15,000 kw. in capacity the number of units and the space occupied by them becomes excessive. Just what their maintenance under the high cylinder temperature will be is dubious, as there are not sufficient data available to enable the Committee to report.

Figs. 16 and 17 summarize the whole prime mover situation in the combined curves of investment and fuel costs, as by taking the sum of the ordinates at any percentage of the rated load it will be seen that the steam turbine is far more economical than any other type of heat engine.

In conclusion the authors wish to acknowledge their indebtedness to Mr. D. W. Mead, a member of this committee, for the curves of Fig. 14 and a portion of the section on hydraulic turbines, and also the kindness of a number of manufacturing companies in furnishing the necessary data.

DISCUSSION ON "PRESENT STATUS OF PRIME MOVERS" (STOTT, PIGOTT AND GORSUCH), DETROIT, MICH., JUNE 25, 1914.

R. Tschentscher: The division entitled "Gas Engines" comprises internal combustion prime movers using natural gas, producer gas, or blast furnace and coke oven gas. The relative measure in which each enters into the problem is not given.

In 1907, blast furnace gas engine installations began in the iron and steel industry. It was my lot at that time to place in service and operate the first plant of any considerable size. Power from the plant referred to was imperative, and there was therefore but little time for miscellaneous experiments, alterations, readjustments, etc. The conditions presented each day were varied. Experienced men were not obtainable, the hours were long, gas headaches were frequent, and the force was ever changing. The blast furnace operating conditions required readjustment from a condition of making pig iron with gas as a by-product used for air heating or steam generation purposes, to a condition where the maintenance of an adequate gas supply was necessary in order to supply electric power for the equipment used in making the pig iron. This proposition presented an entirely different phase to the blast furnace man. If he did not make the gas, the electric power could not be supplied, and hence he could make neither pig iron nor gas. I am afraid, therefore, that in some quarters a knowledge of the earlier more or less unsatisfactory power costs and operating results incident thereto, is still the basis for an opinion as to the status of the blast furnace gas engine in power stations at the present time.

The situation, however, based on the facts has been materially altered. It is true that from 1907 to 1909 the steel industry may have put into operation too many blast furnace gas engine plants, and that the gas engine reputation suffered thereby; but it is now recognized that after the experimental bill has been paid, gas engines operating on blast furnace gas have a footing based on true economics, namely, the return on the dollar invested, all factors considered.

At the present time statistics which I endeavored to collect show that there is approximately 450,000 kw. generating capacity in the steel plants that sent returns to me. Of that capacity, approximately 175,000 kw. use gas engine generation. The United States Steel Corporation alone has installed and in service approximately 140,000 kw. of gas engines operating from blast furnace gas. The various sizes of the plants range from 1000 kw. to 64,000 kw. in one plant.

About a year ago a paper was read before the Iron and Steel Institute, in which were given blast furnace gas electric power station costs, not including investment costs or other fixed charges, that were, approximately, $2.75 per 1000 kw-hr., being 2.7 mills per kw-hr. These figures were the results of a year's operation, 1912, I believe. These figures covered the operation of units, most of which were of the earlier type. Since that time the situation has materially changed. A 2000-kw. unit is not the limit of size by any means. Manufacturers are prepared to build now, and have had in operation for some time, units of 3000 kw. The exact weights I do not recall, but the weight per kilowatt for the 3000-kw. unit is much lower than it is for the 2000-kw. size. The operating costs for a plant composed of 3000-kw. units, as now manufactured and as operated for at least two and a half years, are lower than 2.7 mills.

J. R. Bibbins: Does that include the investment?

R. Tschentscher: No, the figures do not include investment. They are what is customarily considered as power station cost.

I wish to comment on a few specific points mentioned in the paper. In Fig. 16 are given fuel costs for a 750-kw. unit. For fear these may be taken as representative of what the gas engine can do, I will say that from my knowledge of the subject it appears to me to be not equitable to compare the 750-kw. unit with the turbine or reciprocating engine of that capacity. I am discussing this subject merely from the standpoint of blast furnace gas engines, not natural gas or producer gas engines. A steel plant requiring but 750 kw. would far better install a steam power prime mover or buy its power from some other source, because such a plant will probably have considerable periods in which there will be no gas available and no furnace in operation, and hence no power can be generated from the gas engine installation. I think it may be stated as a fact that the 750-kw. gas engine has no place in the steel plant. Therefore, comparison by using such units, as far as the blast furnace gas engine is concerned, may be misleading.

On the page following Fig. 16, the cost of $3 per ton is used as the cost for fuel in the relative comparisons, which, I believe, is too high when considering cost of fuel as used by steel plants. Most steel plants are located at a point of low fuel cost, and $2 would more nearly represent the true condition.

In the last paragraph of that page it is stated that the steam turbine has an overload capacity of approximately 25 per cent for 24 hours, while the gas engine is credited with an overload capacity for short periods, two hours or even less. That may apply very well to the motive power end of the unit. A steam turbine, no doubt, can operate for 24 hours a day at 25 per cent overload. To a large extent the gas engine may or may not be able to do that, depending on the design, depending on how free the manufacturer was in his guarantee. However, as far as the generator is concerned, I cannot see why the generator on the gas engine cannot have the same overload capacity for the same length of time as that of the turbine or the steam engine, provided they are built on the same standards.

Fig. 17 refers to some interesting data, namely, the cost of 20,000-kw. steam turbine units. I presume that what was intended here was a comparison of the motive power end, the prime mover end, of a plant having 20,000-kw. capacity. If that is the case, it does not appear to me to be fair to allow one 20,000-kw. turbine as the capacity of a 20,000-kw. station. No one, of course, would so design it. It would be designed with two 20,000-kw., or three 10,000-kw., or four 7500-kw., or perhaps two 15,000-kw. units, depending on the overload capacity, in case one unit is shut down. The reason I mention that is this—the 20,000-kw. turbine is compared with ten 2000-kw. gas engines. Ten 2000-kw. gas engines such as may now be purchased, I believe will have a greater yearly kilowatt output than one 20,000-kw. turbine unit. Therefore, it appears to me that a much fairer comparison would be to arrange the curves to refer to a 20,000-kw. output station, each prime mover being of the most suitable size. This might, in the case of the gas engine plant, consist safely of eight 3000-kw. blast furnace gas engines or perhaps seven. I will not attempt to say how many oil engines, as I am not familiar with the subject. On this basis the situation is altered, and these curves will assume an entirely different shape. Eight 3000-kw. gas engines may be purchased for materially less than $65 per kw., installed on the foundations. Not having the figures definitely at hand, I am, however, of the opinion that $50 or less will purchase the equipment.

The table at the bottom of page 1163 deals with the total investment cost of gas engines and other prime movers, and I see it is stated that the cost of the producer gas engine is $140 per kw. Unless the price of producers has materially increased, I believe that is a high figure. When I first made my comments or notes here in connection with this particular table, I did not see that "producer gas" was put in parentheses. Some have the opinion that the blast furnace gas engine installation will run in the neighborhood of $140. It can be installed for materially less than that, not including, of course, land values, which vary so greatly, depending on location. Without considering land values, I believe a 30,000-kw. plant may be installed for from $85 to $100 per kw., including the gas cleaning plant, together with the necessary piping, all auxiliaries, etc.

On page 1165 the question of reliability is mentioned, giving the steam turbine by far the best of the argument. In that connection I wish again to say that the situation is materially different from what it was several years ago. The history of the operation of one particular plant for the past few years shows very reliable blast furnace gas engine operation—probably as reliable as a steam turbine plant, with the exception of, perhaps, a little unreliability in this local plant in the gas supply end, due to periodically restricted furnace operations. As far as the power station operation is concerned, modern gas engines are practically as reliable as steam turbines. It must be remembered that blast furnace gas engines operate twenty-four hours a day, because the mills operate on a twenty-four hours per day basis.

A paragraph on the last page of the paper deals with the question of space economy. It is stated that a gas engine installation requires twenty times the space of a horizontal steam turbine installation. When that figure was presented to me I pictured an 8000-kw. plant with which I am familiar and tried to figure whether I could replace that with a 160,000-kw. horizontal turbine outfit. I am perfectly safe in saying I could not. I could probably put a 70,000-or 80,000-kw. horizontal steam turbine plant in that space.

I would like to call the attention of any one who is interested in the subject of producer gas engines to the installation which the Ford Motor Company is now in process of making. There will be three 3750-kw. generators, direct-connected to twin tandem combined gas-steam engines, a very unique installation. What they will realize I do not know—one side of the outfit being steam-driven and the other producer-gas-driven; the boilers to be mounted above the producers, and the feed water to be heated from the waste gas of the gas engines. I understood in conversation this morning with one of the representatives of the company, that they have overcome the usual difficulties, and on that basis we are likely to see some exceedingly economical results obtained at that plant.

In conclusion, I would like to say that the paper which has been presented to us this afternoon is of very great value, but one is apt to draw erroneous conclusions from a paper which treats of prime movers only, and it ought to be emphasized that all these figures should be taken as representing prime movers only, and not as being typical of the entire generating plant. Operating conditions and costs of the boiler plant, the producer plant, or the gas cleaning plant, or similar factors relative to auxiliaries, may greatly modify the conclusions which may be drawn from a consideration of prime movers only.

J. R. Bibbins: This admirable paper brings forcibly to mind two fundamental facts both intimately related to the cost of power production: (a) the tremendously rapid increase in the capacity and the cost and weight efficiency of steam turbine units; (b) the correspondingly rapid aging of power generating apparatus by change in the art, and the heavy replacement or obsolescence charges resulting therefrom.

The one is evident on the face of the facts presented, the other, by experience only, and yet in an established property the burden of fixed charges due to obsolescence must be reckoned with and might operate to modify largely the relative economic positions of the various prime movers represented in this paper. It is to be hoped that the authors will present something further on this aspect of the question in the future.

While the general economic principles employed in this paper are quite unimpeachable, it seems to me that forced comparisons between the relatively small units of the internal combustion type and the large units of the steam turbine type can hardly lead to conclusions fundamentally sound in the broader aspect of *system* vs. *size*. Thus the comparison drawn here for a 20,000-kw. plant is justifiable only in so far as it applies to the forced conditions of ten gas units vs. one steam unit. Obviously neither installation would receive serious consideration to-day as an effective layout, and a true comparison of systems should be made on smaller capacities. Thus in Fig. 18, the heat consumption curve of a 2000-kw. turbine would appear to much less advantage than that of the 20,000-kw. unit.

It is well that the authors have brought out the importance (page 1142) of the Rankine cycle as a detector of spurious water rates or heat consumption curves. I have in mind the case of a heat engine economy curve published some years ago as a wonderful performance. It looked rather "fishy," and I did not take even the trouble to work out the thermal efficiency, but simply applied the Willans law, as in Fig. 1. This very simple graphical method plainly showed that the heat consumption curve published was in error.

I am interested to know whether the net basis of heat units has been used in making these comparisons. Of course, either net or gross would not affect the *over-all* efficiency of a plant, at the coal pile, but it would most decidedly in the comparison of these thermal efficiencies. Also, approximately uniform gas engine piston speed was presumably used in making these comparisons of engines of various sizes. In the matter of the oil engine, while some of the auxiliaries might be dispensed with, I do not quite see how the air compressor can be disregarded. It is rather difficult to conceive of a Diesel type of engine without any auxiliaries, because the engine is absolutely dependent upon the air injection for its operation.

In Figs. 16 and 17 the authors have presented an argument that seems rather hard to combat, with two exceptions. One is the unfortunate choice in the size of units. Thus, in this comparison between the 20,000-kw. steam unit and the ten 2000-kw. gas units, it is important that these costs and economy curves should be correlated not only as to size, but as to method of operation. It should be assumed that the smaller units were put into operation consecutively. That is, 50 per cent plant rating should refer to *half load* on the 20,000-kw. machine, and half of the number of smaller machines running at *full load*, rather than half load on all of the small machines. I must confess that the latter method, here used, seems unduly unfavorable to the smaller units, because it is obviously possible, in an underloaded plant, to build up prime mover capacity to meet the load with far better over-all efficiency in small units than with one very large unit.

The other point is in regard to the price of steam or gas coal, $3 per ton. It was my pleasure to have quite intimate knowledge of the development of the bituminous producer in the use of low-grade fuels of various kinds. I have not followed very recent developments, but in view of the success attained at that time it seems to me inequitable, except in certain individual locations, to assign to the producer gas plant as high a price for fuel as for steam coal. If the producer has any special field, it is as an apparatus designed for, and capable of, using low-grade fuels—for instance, the lignites in the West. Thus, any possibility of difference in the cost of coal (Fig. 16), would operate to overcome the higher investment cost assigned to the power gas plant.

Finally, there is one thought which occurred to me in this connection, especially as to the theory of prime movers, and their application, presumably, to central station work. In a previous paper, presented two days ago at this meeting, the question of special peak load apparatus came under discussion, and there occurred to me at that time, as many times before, the question whether the complete standardization of prime movers is absolutely essential in a plant only half of which may be called upon for peak load duty, and not for an hour necessarily, but perhaps for only ten or fifteen minutes. In street railway practise, for example, the maximum passenger movement occurs usually within ten minutes after 5:30 p.m. The reflex of this great volume of passenger movement on the power plant load does not by any means last over the hour.

Now, on the other hand, generators are universally rated upon at least an hour basis, and the question therefore arises, whether it would not be possible to develop a type of prime movers or combination of prime movers, of minimum cost, perhaps not quite as efficient (because the last grain of efficiency would not be necessary at the extreme peak), but of a type exceedingly sturdy in construction, one that could stand higher temperatures and excessive overloads for these short peak load periods. Of course, the steam turbine is able to do this now, though not designed *primarily* for peak load conditions. Perhaps a special combination of short peak ratings would suffice. It would be interesting to know how near power plant apparatus, as it is designed today, approaches the limit of ultimate capacity of materials used. It certainly is not impossible to determine this in the case of the gas engine installation, which, as you can see, is very seriously handicapped on the peak load basis.

H. M. Hobart: The authors give a table at the bottom of page 1163 in which the total investment cost per kilowatt is given. With the greatly decreased cost of steam turbines, the cost of the prime movers and the generators is now perhaps one-half, or even less, of the outlay for land and buildings in the case of a station located in or near a large city. It would be interesting if, in the first column of this table, the authors would indicate more precisely whether the total investment cost per kilowatt, at any rate in the case of steam turbine plants, includes a station to be laid down in or near a large city.

I want to call attention particularly to this matter of total investment cost. I should be glad if the authors would qualify that figure of $65 for the total investment cost per kilowatt for the steam turbine plant, given in the table at the bottom of page 1163, with a precise statement of the allowance they have made for the land and buildings in the case they have in mind, since that is probably the largest component of all, and leaves us in a very vague frame of mind as to the composition of the total investment. Figures should preferably be given for each particular component of the total investment, and I should like to ask the authors to supply these component costs. It would be much appreciated if the authors would make a precise statement of the total cost in and near large cities, and also the corresponding allowance for land and buildings. This could be followed by the corresponding figures for the same size and design of station, but located exclusively with reference to an economical supply of coal and water and low prices for land. The addition of these data would be much appreciated.

E. D. Dreyfus: The admitted breadth of the subject of prime movers makes it possible only to treat of all of its phases but partially in a limited paper; however, sufficient has been presented to demonstrate that the steam turbine holds a superior position in view of the present prices of the different types of equipment and the existing fuel costs. Such an attitude regardlng the equipment situation has been quite pronounced in the power industry during the past two or three years. As pointed out in the paper, the steam engine has for some time been rapidly losing ground. Greater use of the gas engine has been seriously checked by the lagging progress of the producer. While natural gas is an ideal fuel for the internal combustion engine, the available supply for power purposes is limited and therefore its price is too uncertain. Very little practical headway has been made in the utilization of the inferior grades of fuel such as peat, lignite and the low-grade coals.

While the gas engine has taken a prominent position in blast furnace and steel mill work, I do not believe it can fairly claim an undisputed title to that field. Possibly for a limited capacity it may show a small economic advantage. However, when the plant becomes of an important size the advantage in fuel economy not only vanishes, as illustrated in the paper, but the gas engine is exceedingly handicapped by its greater maintenance and attendance costs. For such reasons the gas engine will be unable to maintain its former popularity even among the steel men.

The writer made the statement about three years ago that the demand for gas engine plants would only be for installations of 1000 kw. or less, until there should be a material rise in the price of coal. Expected further developments in gas power equipment have also, no doubt, deterred the power plant owner from installing this type of equipment.

It might be well to illustrate by example the bearing the item of labor has upon the total operating cost. The labor cost in a gas producer plant containing three 300-kw. units would be about $830 per month, while for a similar size steam turbine station it would be in the neighborhood of $570. For such small size plants the difference may not be serious, but on the other hand, if we were to compare plants say of three units of 2000 kw. each, the gas engine station would involve a labor cost of about $3425, while the same capacity steam station would demand only $2020, roughly. If we take a plant of 20,000 kw., consisting, in the case of gas engines, of ten 2000-kw. units, and if steam turbines are used, of about four 5000-kw. units, the respective labor costs would be in the neigborhood of $11,180 and $4,475 per month. As the fuel economy of the gas

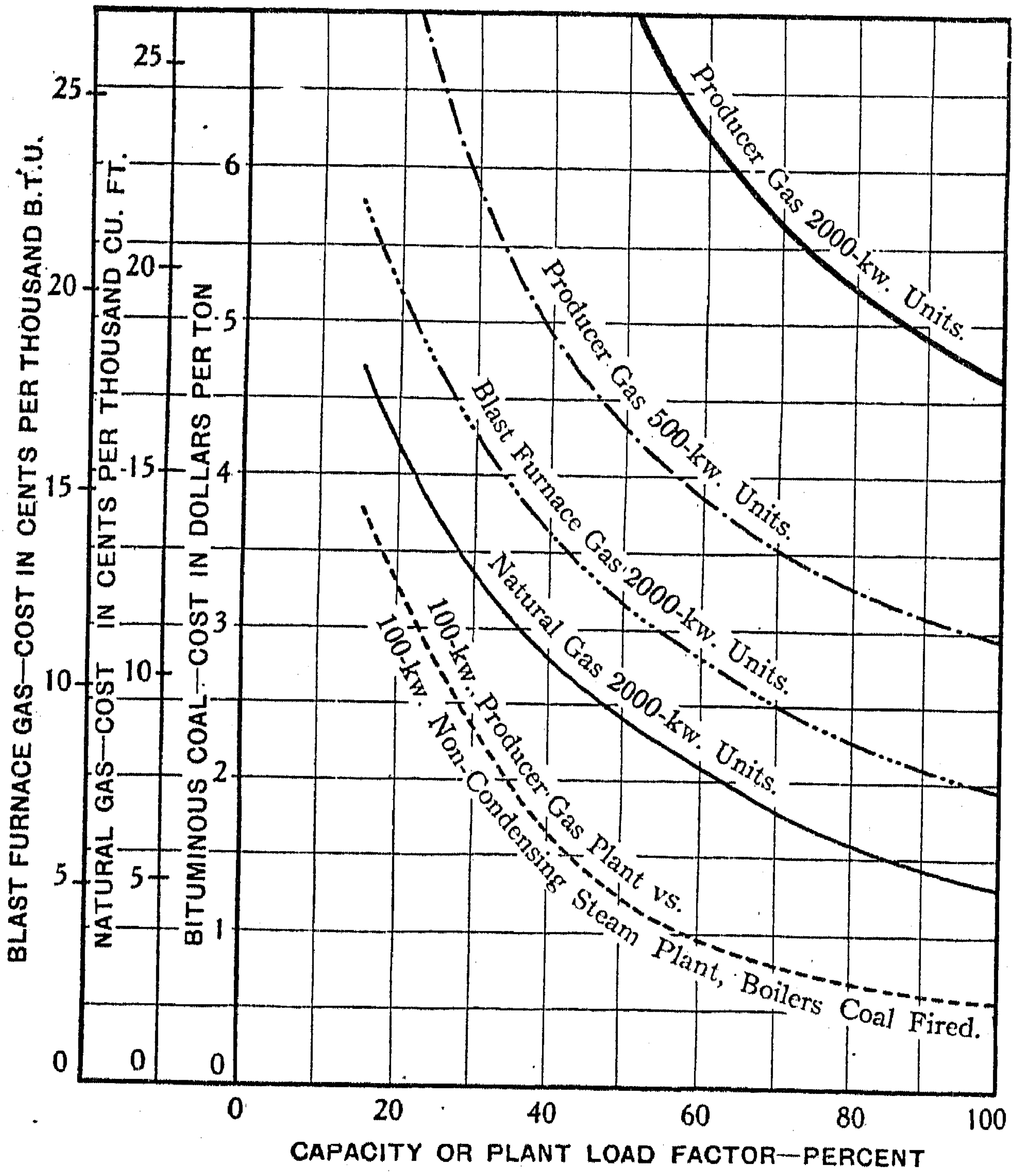

FIG. 1—PROPORTIONATE EQUALITY CURVES

Showing balance of total costs of generation in gas and steam plants with variable fuel prices and load factors.

Area above curves favors the gas engine; below, the steam turbine plants prove more economical. Based on general conditions in the text.

Fuel values

Bituminous coal	13,000 B.t.u.
Natural gas	975 B.t.u.
Blast furnace gas	80 B.t.u.

engine is but little better than the steam station when such sizes are considered, and, moreover, as the labor cost in the gas engine plant exceeds one-third the total operating expense, the internal combustion engine is obviously given a decided setback. This contrast has been made upon the basis of a 50 per cent load factor. The lower the load factor, the less economically will the operating force be applied, as a general proposition, so that labor cost will in a somewhat greater degree prejudice the gas engine plant at low load factors. It is rather difficult to show all the combination of factors at work to influence operating cost under the wide range of conditions that obtain.

I attempted to show, in a paper presented before the Association of Iron and Steel Electrical Engineers in 1911, the general relations of the different prime movers by taking into account all the elemental factors. As germane to the discussion, I am presenting (Fig. 1) one of the figures prepared at that time, which shows results obtained by taking into account all the different costs that enter into the power problem. Excepting the bottom curve, all the comparisons are between gas engine plants and steam turbine plants. The area above the curves favors the gas engine, and conversely, that below represents the economical field of the steam turbine. It will be observed that for large gas producer stations operating on low load factors, the cost of coal would have to be at some fabulous price to justify their existence. In the hydroelectric plant it is not only the absence of fuel that makes for low costs (assuming reasonable development cost), but the small operating and maintenance expense gives such a plant an excellent position when within close range of a favorable power market.

Referring to costs of oil engines, some recent figures obtained from a large American manufacturer indicated that the complete oil engine plant could be installed (including buildings and foundations) at costs ranging from $150 down to $100, depending upon the size of the plant. A representative of a foreign oil engine builder claimed that oil engines could be delivered and erected within reasonable shipping distance from port of entry, complete with building, at costs about 20 per cent below the figures just given. This is expecting a little too much, but the oil engine builders are working towards a reduction in the cost of the equipment, which should of course give this type of equipment a better competitive position. On the other hand, the lack of stability of oil prices has a disquieting effect upon the use of the oil engine. In the South and Southwest in the vicinity of the oil fields or in the neighborhood of the ports receiving Mexican crude, the oil engine increases in importance.

In any consideration of prime movers it is becoming better understood right along that we can not allow ourselves to be guided by technical conditions only. The human element enters seriously into a question of this kind. For a given equipment the results obtained under actual operating conditions may differ in a marked degree, depending upon the ability and conscientiousness of the chief and his crew. This is more apparent in steam plants, as, with their liberal overload capacity, the output may be maintained though the efficiency may have fallen off greatly. With the producer gas engine plant, in the first place, a more competent force is required, and then if the force should become negligent the quality of the gas will suffer and at the same time no doubt there will result an inefficient mixture, so that the engine may fail to pull the load. Therefore, it may be said the gas engine will depart the least from its best operating efficiency. Another point—if the external load on the station is of a widely fluctuating character, the unit or "machine" load factor will be unfavorable, on account of the inadvisibility of operating without a conservative margin. In fact, if a gas engine is overloaded to any extent it is liable to fall out of step, and if the station comprises gas engines only, the effect becomes progressive and the whole plant will go down. I have observed complete shut-downs from just such causes. There are a great many operating considerations to be borne in mind, and this is unquestionably accountable for the marked inactivity of the gas engine business in the past few years.

H. G. Stott: Mr. Tschentscher is entirely mistaken in assuming that these comparisons refer to blast furnace gas practise, as that is specifically exempted. The blast furnace gas plant is not considered in the paper, excepting the reference on the page where we begin discussion of the gas engine, that is, on page 1142, where you will find due credit is given to the position of the large gas engines in steel plants, where we say, "The development of large gas engines is largely due to the ideal conditions existing in steel industries, where large quantities of blast furnace gas are available, requiring only cleaning to make a perfect fuel for this type of prime mover." Then we go on and refer to the fact that they have reached a capacity of 6000 brake h.p. for a single unit of the twin tandem type.

Now, some question was raised by Mr. Tschentscher and also by Mr. Bibbins, as to the comparison of costs of producing power, based upon the assumption of equal cost of fuel. I admit that possibly may be a little unfair, but how are you going to do it in any other way, in making comparisons? If we use cheaper fuel for the gas engine than we do for the steam turbine, there would be a complaint from the other side, because, as you know, in a great many cases, anthracite is used in producer gas engines, and anthracite is usually—not always—but in the larger sizes, is much more expensive than bituminous or semi-bituminous, so I think it is clear that for the purpose of comparison it was an impossibility for us to do anything but use the same price of fuel in both cases, because any needed correction can be made in this comparison. If, for example, you find the fuel to be used in the producer is 10 per cent or 50 per cent cheaper, it is quite easy to make this correction in these curves. If we had started on an unequal assumption of price, it would have been very difficult to make the correction.

Mr. Bibbins asked about the kind of heat unit, whether gross or net heat unit. I do not understand the question, but I would say that we used the mean B. t. u., which is the average B.t.u. contained in steam between a temperature of 32 deg. and 212 deg., which is given in practically all the modern steam tables, which is 1/180 of the heat contained between two points, between 32 deg. and 212 deg.

There were a number of other questions raised, which I will be glad to answer further by a written discussion, as our time is limited now.

Of course, in making these comparisons it is obvious you must make generalizations. We have compared in one table here the results of all units; for example, in Fig. 16 we go up to a maximum size of 750-kw. units, but, in order to be perfectly fair to the larger prime mover, namely, the steam turbine, it is obvious we had to consider 20,000-kw. turbines. We might have gone to the 30,000-kw. turbine, as that is now an ordinary type and design; however, we only went to the 20,000-kw. turbine, as there are a number of those in actual operation today. There was no way, which we could see, to compare the operation of the 20,000-kw. unit, as a unit, other than to take a number of multiples of the smaller ones to compare with it. So far as we know, the largest gas engines in actual operation, outside of the steel industry, are those of 2000 kw. rating, and therefore we chose that size, and the same reasoning applies to the oil engine. If we multiply that by two in one case and by fifty in another case, it does not alter the relative value, and simply quoting the three machines, so as to make them comparable, is not fair to the steam turbine, unless we show what can be done with the larger sizes. That is the reason we did it.

The paper is also criticised as not covering the entire cost of the power plant. This paper is one on prime movers, and not on power plant. It seemed to us that we had to take into consideration the fuel consumption, but that we could cut out all auxiliaries. The consumption of power by the auxiliaries of the various types of prime movers is not greatly different in relative cases. The total percentage of power is from 6 to 8 per cent in nearly all cases, so that we had to make certain assumptions in order to make these comparisons on what seemed fairly equal terms.

S. Barfoed (by letter): This paper is a résumé for conditions in that section of the country where coal is obtainable at reasonable prices. In large sections of the West, however, oil is the common fuel, and the curves given under "Finance and Economics" must be revised for this condition. Assume the oil to have 18,000 B.t.u. per pound, then with oil-fired boilers at full load a kilowatt-hour can be had from 1.26 lb. of oil, corresponding to about 259 kw-hr. per barrel of oil. With oil at 4 cents per gallon the fuel cost at full load and with oil-fired boilers will be 6.5 mills.

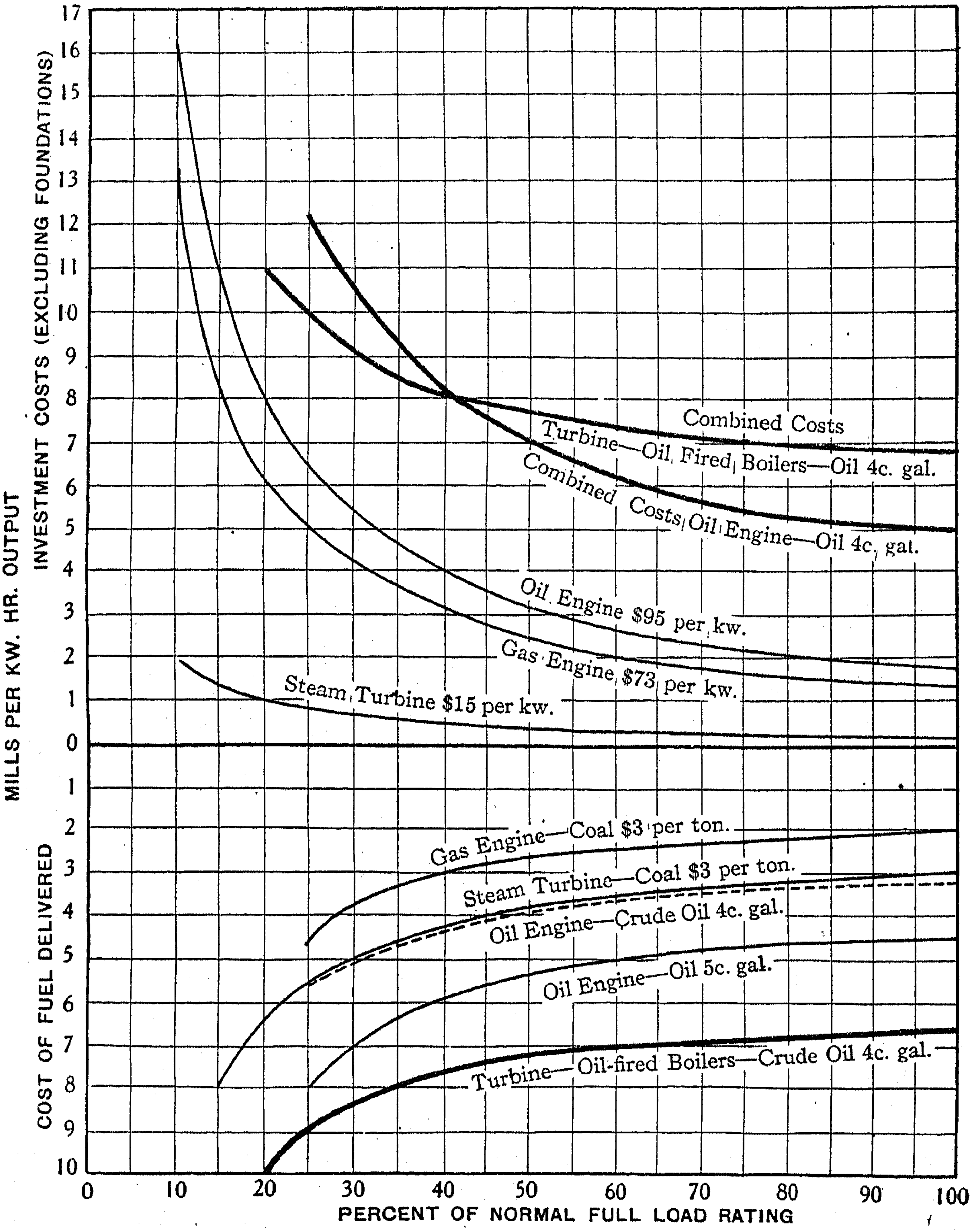

FIG. 2—RELATIVE INVESTMENT AND FUEL COSTS

Of 750-kw. steam turbine (one curve for coal firing, one for oil firing), gas engine, and oil engine, including direct-connected 60-cycle generator, operating at different percentages of normal full load.

In Fig. 2 there have been reproduced the curves of Fig. 16 in the paper and a curve has been added for a turbine with oil-fired boilers. Combining this curve with the curve for investment costs, and also the curve for the oil engine with oil at 4 cents a gallon, with the corresponding investment cost curve, it is seen that the oil engine has a considerable margin over the turbine from full load to half load. With increasing oil prices the margin would be still greater.

Franklin M. Farwell (by letter): It seems to me that the authors, without so stating, are thinking largely in terms of great capacity power stations. Almost all well-informed engineers will concede that for power stations large enough to admit of the use of units of 20,000-kw. capacity the steam turbine has no competitor, with the possible exception of water power, but when it comes to the matter of small stations it is a different story, and I believe that many engineers will question the authors' conclusions when applied to power stations of a size where all forms of prime movers are on a comparable basis.

The paper dismisses with a few brief words the reciprocating engine as if it were something not worth considering. No mention was made of a form of generating plant popularly known as the "locomobile." Many prime movers of this type are in use in various parts of the world and at least two concerns are selling them in this country now. These engines are especially adapted for driving generators of 600 kw. or under and many tests have demonstrated that the thermodynamic efficiency closely approximates that of the gas engine, and there are many who will question the ability of the present steam turbine to equal, much less exceed, these efficiencies, except in view of the possibilities offered by the mercury boiler and turbine as brought out by Mr. W. L. R. Emmet (see TRANS. A. I. E. E., 1913, Vol. XXXII, Part II, p. 2133). These entire units, auxiliaries included, will cost about the same as a gas engine of the same rating, and very high efficiencies are covered by the manufacturers' guarantee.

In Fig. 16 in the paper, the authors attempt to make a comparison of the various prime movers on the basis of units of 750-kw. capacity. As the curves in Fig. 16 stand, the investment cost for the oil engine is eight times that of the steam turbine and that of the gas engine approximately six times that of the steam turbine. A little further on in the paper is a table giving the total investment cost per kilowatt of stations using various forms of prime movers. According to this table the cost of an oil engine station is less than twice the cost of a steam turbine station, while the cost of a gas engine station is only slightly over twice the cost of a steam turbine station. There is a very evident discrepancy here. This discrepancy is doubtless due to the fact that in Fig. 16 the investment cost in the case of the oil engine covers practically a complete generating unit, but in the other cases only part of the complete generating unit is considered, as the producer in the case of the gas engine and the boiler in the case of the turbine are left out of consideration. It seems to me that this is a decidedly unfair comparison; that the producer in the case of the gas engine and the boiler in the case of the steam turbine are the primary generators of power and cannot consistently be left out in comparison with oil engines.

As the high economy of fuel in a steam turbine is largely dependent upon a good vacuum and high superheat, in other words, is to a considerable degree dependent upon expensive

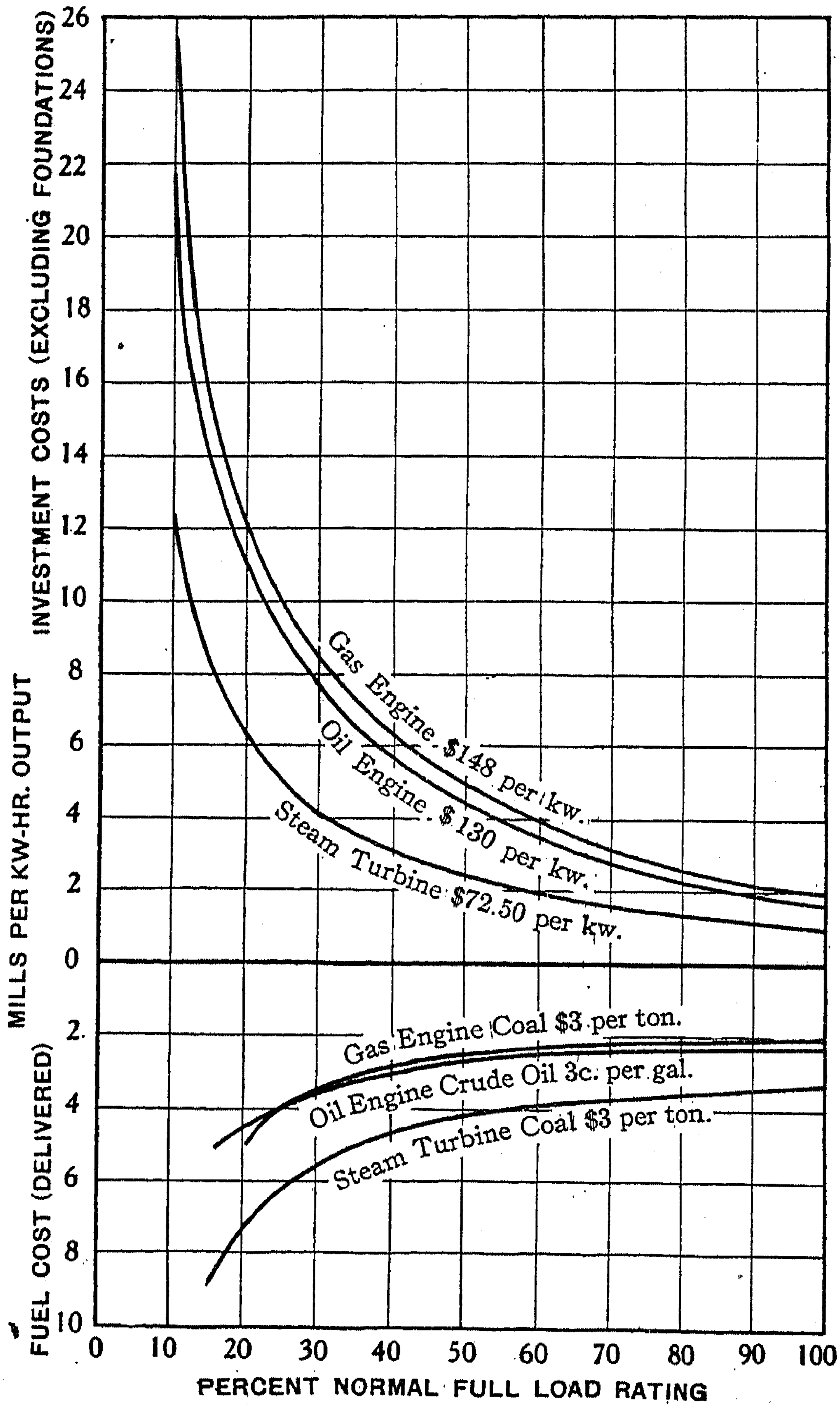

FIG. 3

auxiliary equipment, it would seem no more than fair to include the auxiliaries. Much has been claimed for the small space required for the steam turbine, but in most such comparisons no account is taken of the boiler plant. If the boiler plant is considered when comparing the space economy of the steam turbine with oil engines for small power stations, the steam turbine does not appear to have much advantage. In view of this it seems to me that total station cost is the only fair basis for investment cost comparison.

The table of total investment cost per kilowatt included in the paper gives values for a large capacity station, but if we add to them the engine cost differences between Figs. 16 and 17, viz., $10 for oil engines, $8 for gas engines and $7.50 for the steam turbine, we have $148 for the gas engine, $130 for the oil engine and $72.50 for the steam turbine, which would seem to be reasonable for a station using 750-kw. units. On the basis of these figures I submit, in Fig. 3 herewith, a revision of the curves in Fig. 16. Concerning the lower part of the figures, showing the fuel costs, I desire to state that it seemed to me that the values given for the steam turbines are rather lower than are commonly found for working conditions, so in the accompanying curves I have boosted up the values to what seem to me to be more reasonably attainable figures with turbines of such small size. Concerning the oil engine, I find that there are several authentic cases where the total operating cost, exclusive of attendance, is considerably below that given in Fig. 16 for fuel alone, and that there are regions where crude oil can be purchased for as low as 2.5 cents per gal. In the curve submitted I have used 3 cents per gal. I believe that some of the manufacturers of oil engines are willing to guarantee a higher thermal efficiency than that given in the paper, but I neglected that in the curves. The fuel costs for the gas engine I did not find any reason for changing. It seems to me that the curves in Fig. 3, at least insofar as they concern the investment cost, are a much fairer basis for the comparison of prime movers for small plants than the curves submitted by the authors of the paper.

By adding the ordinates for investment cost and fuel cost in the curves I have given, it is apparent that there is very little difference among the three forms of prime movers. If we consider even smaller stations, say those with units of about half the size of those considered in the curve, the oil engine and the gas engine will have a decided advantage over the steam turbine. It is worth while to note in the case of the gas engine and oil engine that jacket water and water heated by exhaust heat economizers can be used for heating and for industrial processes where hot water is needed, thus extracting still more heat from the fuel without in any way affecting the engine efficiency.

I do not think that any one type of prime mover can be made to meet all cases. I believe in selecting the one best adapted to the local requirements.

While there are many central stations of enormous capacity, still a very large percentage of power generated, particularly in industrial plants, is produced in stations using units of 750 kw. or less, so it seems to me that the paper under discussion, considering the scope it is intended to have, hardly gives the status of prime movers for small stations with the fairness that ought to be expected.

W. S. Gorsuch (by letter): Curves shown in Figs. 16 and 17 have been criticised as being unfair to the oil and producer or natural gas engines. In Fig. 16 the largest oil engine for which reliable data could be obtained was taken as the basis, and a corresponding size gas engine and steam turbine selected for comparative purposes. In fact, the largest oil engine unit in successful operation in this country today is less than 500 h.p. capacity; therefore, in taking a unit of 750 h.p., the oil engine is being favored.

The object of Fig. 17 is to show the advantage that the steam turbine has in being made in large sizes, 20,000 kw. being taken, as many such units are in actual operation. To make the curves showing investment costs comparable, the cost per kilowatt normal rating was determined on the basis of purchasing 10 producer gas and 40 oil units of the largest sizes in actual operation today. The lower curves show the relative economy of the individual units and have no reference to plant operation.

Regarding Mr. Tschentscher's comments on " Space Economy," the figures given on the last page of the paper are the average minima and maxima of different sizes of machines in actual operation today, excluding the blast furnace gas engine.

If Mr. Farwell will refer to page 978, under the heading "Finance and Economics" he will find it specifically stated that the scope of this paper is limited to prime movers; consequently the upper curves in Figs. 16 and 17 show the investment costs in units per kilowatt-hour output at various percentages of full-load rating for prime movers only, that is, the cost of prime mover installed, exclusive of foundation. The figures given in the table on page 1163 give investment costs of plants using various types of prime movers, and include all costs, with the exception of real estate.

The figures and curves submitted by Mr. Farwell are based on the assumption that the investment cost per kilowatt installed capacity of all the items contained in a small power plant, exclusive of the prime mover, will be the same as for a station of much larger capacity, which obviously is erroneous. The cost of fuel per kilowatt-hour output for the steam turbine, as given in Fig. 16, is based on the average efficiency obtained from this size machine.

R. J. S. Pigott (by letter): Replying to Mr. Tschentscher, if he will refer to page 1143, under the heading " Capacity," no doubt the question in his mind will be removed as to the relative overload capacities on gas engines and turbines. While his figures in criticism of our costs are somewhat indefinite as a basis of analysis, the figures presented in our paper were obtained from a number of manufacturers and from purchase prices in the hands of a number of buyers.

Referring to the statement of Mr. Farwell concerning the locomobile: This type of prime mover has been installed in this country in less than half a dozen small plants, the first early in 1913. Few or no maintenance data are available, but it is certain that with the high superheats employed, the maintenance will not be less than with the ordinary reciprocating engine using superheat. The inflexibility of a type in which one boiler is definitely tied to one engine is a very pronounced objection. The very high "efficiencies" usually quoted, are water rates, which naturally, with the high superheat and re-heat employed, are low, but low water rate is not necessarily concomitant with high efficiency.

Referring to the Rankine cycle, the performance of locomobiles is little better than that of ordinary reciprocating engines. Table I, herewith, taken from tests of the first American locomobile, published in *Power* May 20, 1913, shows this. With similar superheat and re-heat the turbine would do equally well, and if worth while to do it, could readily be arranged in a similar manner to the locomobile.

TABLE I

Test	Brake h.p.	Lb. Steam b.h.p.-hr.	Pressure lb. gage	Vacuum, in. of Hg.	Superheat	Thermal eff'y	Efficiency ratio
3	127	10.82	196.5	27.1	256	18.7	62.5
4	148	11.08	206.5	26.62	275	18.3	60.7
5	115	10.9	201.5	28.58	237.6	18.2	55.9
6	154	11.15	198.5	27.27	253.5	17.5	57.7
7	162	10.25	201	27.23	262	19.4	62.8
10	77	11.65	200	27.25	170.4	14.2	48.5

Presented at the 31st Annual Convention of the American Institute of Electrical Engineers, Detroit, Mich., June 25, 1914.

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VOLTAGE TESTING OF CABLES

BY W. I. MIDDLETON AND CHESTER L. DAWES

ABSTRACT OF PAPER

In this country rubber compound, paper, and cambric are generally used for cable insulation. From the formula $S = \frac{0.868\,V}{d \log_{10} \frac{D}{d}}$, the stress at any point in a homogeneous insulation may be determined. The minimum stress and the maximum allowable voltage occur when the conductor is 10/27 of the sheath diameter. The present irrational practise of testing cables should be standardized to conform to this formula or a modification of it.

Over-stressing of the insulation is accompanied by a change of insulation resistance and electrostatic capacity.

No one factor of safety is applicable to every cable system, but one must consider the conditions of operation as well.

In testing the voltage may be applied: (1) by submersion; (2) between the conductor and metallic sheath; (3) between wires. The submersion test is the most severe. A sine wave is desirable for testing purposes, but rarely occurs in a commercial generator under these severe conditions of load. Reactance cannot always be used successfully to reduce the volt-ampere load on the generator.

With a distorted wave an a-c. voltmeter gives only a poor indication of the maximum voltage. The writers have devised an instrument based on the oscillograph principle, with which the maximum voltage may be determined, regardless of wave form.

THE design of cables is largely dependent on data obtained from voltage tests made on commercial lengths. Such tests are usually conducted in the testing-room but are frequently made after the cable has been installed. The importance of this subject has led the writers to present such data as may seem either useful or of interest in connection with the design or testing of cables, and further, to enumerate some of the difficulties encountered in making such voltage tests, together with the methods adopted to eliminate these difficulties.

INSULATING MATERIALS

In this country, three materials are in general use for the insulation of wires and cables; rubber compound, varnished cambric, and paper.

Rubber compound is the oldest, and is the only one that can be used under all conditions without the aid of a lead sheath. Its composition is more complex than that of the others, involving pure rubber, certain mineral ingredients, and hydrocarbons. The number of such ingredients and the proportion of each that can be used has allowed a great number of compounds to be made and has led to considerable discussion as to the value of some of these as insulating materials.

Paper as an insulation for wires and cables is used in two ways: wrapped on loosely and kept dry, as in telephone cables, or put on tightly and saturated with some good insulating oils or compound. The insulating properties of this class of cable depend absolutely on the soundness of the lead sheath.

Varnished cambric is the most recent material used for cable insulation and stands between rubber and paper; it has a number of good qualities. Being a cotton fabric coated on both sides with several films of insulating varnish, it is almost waterproof, and may be submerged in water for a considerable length of time without undue deterioration. In the process of manufacture, the varnished cloth is applied spirally in the form of tape, a viscous insulating compound being simultaneously applied between layers.

VOLTAGE AND STRESS FORMULAS

Theoretically, the stress at any point on a homogeneous cylindrical insulation may be determined from the following formula:

$$S = \frac{0.434\ V}{X \log_{10} \dfrac{R}{r}} \qquad (1)$$

where V = volts impressed between conductor and sheath,
r = radius of the conductor,
R = radius of the insulation,
X = distance from the axis to the point in question,
S = stress in volts per unit thickness of insulation at this point.

The stress will be a maximum at the surface of the conductor. Therefore letting $X = r$, $r = d/2$, and $R = D/2$, the stress at the surface of the conductor becomes

$$S = \frac{0.434\ V}{\dfrac{d}{2} \log_{10} \dfrac{D}{d}} = \frac{0.868\ V}{d \log_{10} \dfrac{D}{d}} \qquad (2)$$

where d = diameter of the conductor,
D = diameter of the insulation.

This relation is shown in Fig. 1.

With D and V fixed, the maximum stress at the surface of any insulated wire will be inversely proportional to $d \log_{10} \frac{D}{d}$. It will therefore diminish with an increase in the diameter of the conductor, until a minimum is reached, after which the stress will increase with further increase of conductor diameter. This minimum may be found by differentiating formula (**2**), and equating to zero, and the value of d corresponding thereto is found to be $D/\epsilon = D/2.72$ where ϵ is the Napierian base. This relation plotted with volts per mil as ordinates and conductor diameter as abscissæ, is shown in Fig. 1. Point A shows the point of minimum stress. The wire diameter for minimum stress is about 10/27 of the diameter of the insulation.

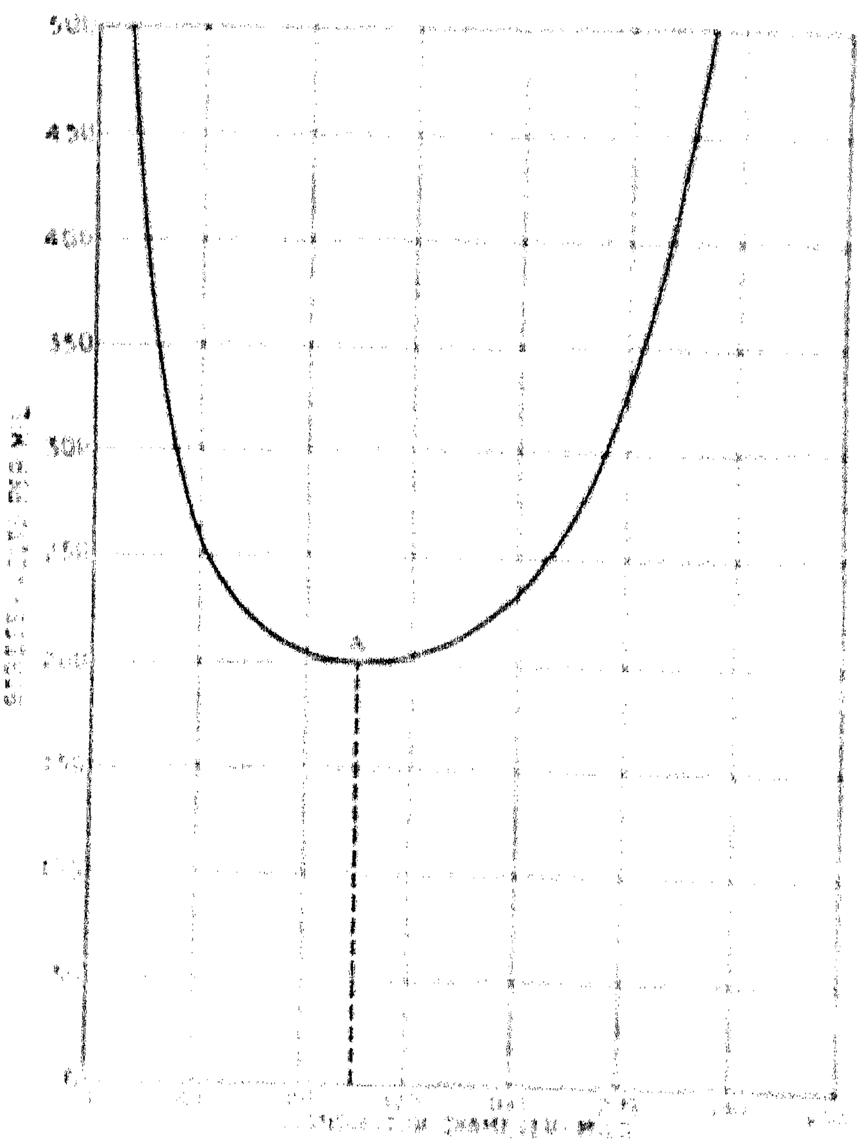

FIG. 1—CURVE OF STRESS AND CONDUCTOR DIAMETER.
Voltage (V) constant at 10,000. Diameter over insulation (D) constant at 272 mils.

If in formula (**2**), D and the maximum allowable stress S are kept constant, and the voltage is allowed to vary with the conductor diameter, we have

$$V = \frac{Sd}{0.868} \log_{10} \frac{D}{d} \qquad (3)$$

This relation is shown in Fig. 2. Under these conditions the maximum voltage that we may impress between the conductor and the outside, without exceeding the allowable stress, occurs when $d = D/2.72$.

This does not mean, however, that if this maximum voltage were impressed upon the cable when d is less than $D/2.72$ the insulation would break down, but rather that the wall of insulation between the diameter $D/2.72$ and the conductor would be stressed beyond the allowable limit. The layer nearest the conductor is under the maximum stress, and the stress in any other layer is inversely proportional to its distance from the center if the electrical characteristics of the insulation remain unchanged. Theoretically, then, all cables having d less than $D/2.72$ should break down at the same voltage, hence follow the line ABC, if it be assumed that the voltage drop across the over-stressed layer is practically zero.

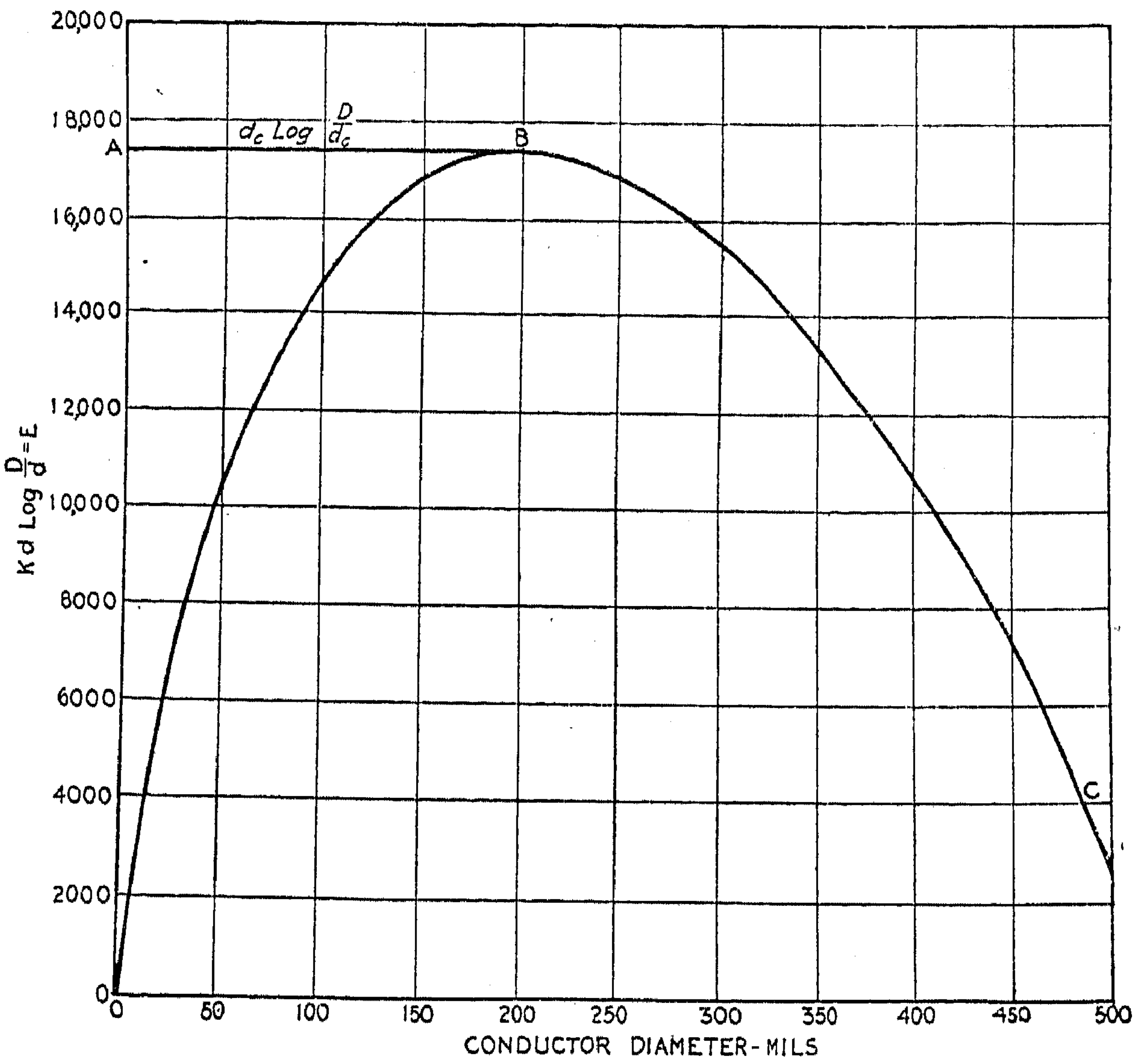

FIG. 2—RELATION BETWEEN TEST PRESSURE AND CONDUCTOR DIAMETER.

$E = K\, d \log D/d$. $K = 200$. $D = 544$ mils. Stress constant.

All wires having the same outside diameter whose conductor diameter is equal to or less than $D/2.72$ ($= dc$) should have the same breakdown voltage.

Although there has been no evidence, so far as the writers know, that these inside layers are actually broken down under these conditions, it is a well-known fact that the dielectric constant of an over-stressed dielectric is greater than the normal constant before breakdown, and this tends to reduce the voltage drop across the inner layers and throw more stress on the outer wall. Whether or not this be true, experience indicates that the breakdown occurs along the line AB, Fig. 2, and little or nothing is gained in making d less than $D/2.72$.

The following formula has therefore been adopted as most nearly representing the breakdown stress for small conductors with a heavy wall of insulation.*

TABLE I

Values of $d \log \frac{D}{d}$. D and d in mils

	Size Wire B. & S.								
Wall (in)	No. 14	No. 12	No. 10	No. 8	No. 6	No. 4	No. 1 Std.	4/0 Std	1,000,000 Cir. Mils
1/32	19.1	20.0	21.3	21.9	22.8	23.9	24.8	25.6	26.2
3/64	25.2	27.1	28.9	30.7	33.0	33.7	36.0	37.6	38.8
2/32	30.3	33.0	36.4	38.0	40.5	42.4	46.0	49.4	51.6
5/64	34.5	38.0	41.1	44.2	47.6	50.4	55.5	59.5	64.0
3/32	38.4	42.2	46.3	50.4	54.4	58.0	64.5	70.0	75.5
7/64	41.6	46.0	50.8	55.6	60.0	65.1	73.0	79.6	87.1
4/32	44.6	49.5	54.9	60.4	65.9	71.0	80.7	89.0	98.4
9/64	47.2	52.7	58.6	64.8	70.9	76.9	88.1	97.6	108.9
5/32	49.7	55.5	62.2	69.0	75.6	82.5	95.5	107.0	119.2
6/32	54.0	60.8	68.3	76.3	84.5	92.5	108.5	123.2	141.1
7/32	57.7	65.3	73.8	82.9	92.2	102.0	121.0	138.9	161.2
8/32	61.0	69.3	78.6	88.8	99.1	110.0	132.0	153.0	180.4
9/32	64.0	72.9	83.0	94.1	105.3	117.3	141.0	166.2	198.8
10/32	66.3	76.2	87.0	98.9	111.3	124.5	150.5	179.3	217.0

$$S = \frac{0.868\,V}{d_c \log_{10} \dfrac{D}{d_c}} \tag{4}$$

where $d_c = D/2.72$.

Potential Stresses in Dielectrics, by H. S. Osborne, TRANS. A. I. E. E., 1910, Vol. XXIX, part 2, p. 1553.

Discussions, by W. I. Middleton, p. 1587; Henry A. Morss, p.1589; Wm. A. Del Mar, p. 1614.

The maximum voltage that may be safely impressed upon a cable of a given insulating material is proportional to $d \log_{10} \frac{D}{d}$, and to a constant K, depending on the quality of material (formula **3**).

Values of $d \log_{10} \frac{D}{d}$ are given in Table I, for walls from 1/32 in. (0.794 mm.) to 10/32 in. (7.94 mm.) thick on various wires from No. 14 B. & S. to 1,000,000-cir. mil cable, and these values are plotted in Fig. 3. These tables and curves are very useful in the application of the formula to cable testing, for the value of K only needs to be known to determine the allowable voltage test or proper diameter. When d is expressed in mils, K varies from 100 to 250 for rubber compounds, is about 250 for cambric, and for paper with thin walls is much less than 250 but is greater than this for walls exceeding 10/32 in. (7.95 mm.).

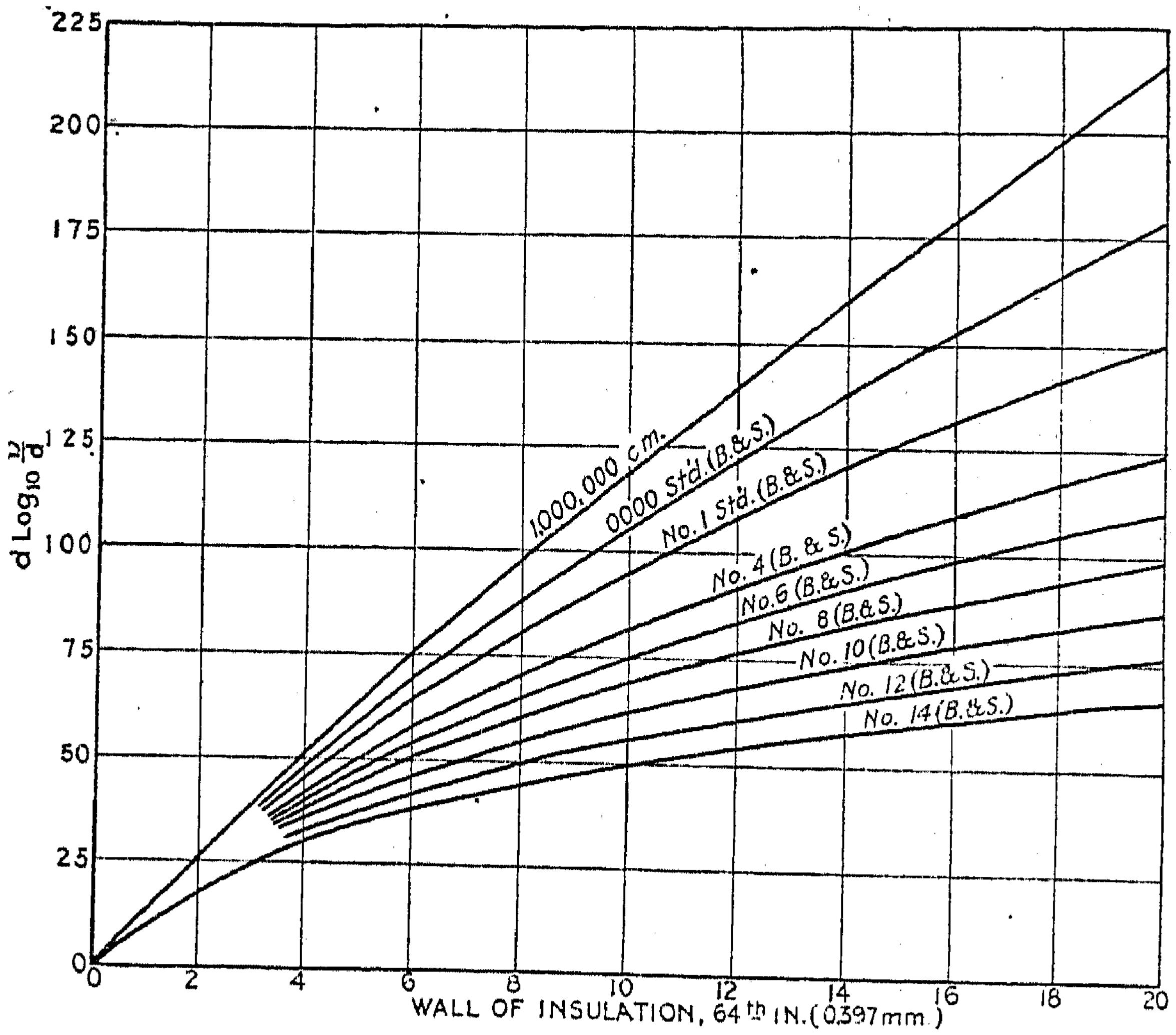

FIG. 3—RELATION BETWEEN $d \log_{10} D/d$ AND WALL OF INSULATION. "d" AND "D" IN MILS

STANDARDIZATION OF VOLTAGE TESTS

Until recently no attempt has been made to standardize voltage tests on insulated wire and cables with reference to the theoretical stress. The result is a chaotic condition of affairs. A very common rule has been to specify a test of 2½ times the working pressure, the feeling being that this allows a good factor of safety. This rule might be satisfactory if the wires were all of one size and the same wall of insulation used for each working pressure. As such is not the case, the only rational way to test all cables is by the $d \log_{10} \frac{D}{d}$ rule or a modification of it.

On October 1, 1905, the Underwriters' Laboratories specified that all Code wires for voltages between 0 and 600 volts should be tested after ten hours immersion in water, with 1500 volts (alternating current) for not less than five seconds. That specification showed the influence exerted on most engineers at that time by the factor of 2½ times the working pressure.

A little study of Fig. 3 together with the sizes of wires and walls of insulation made under the code specifications shows how absurd this test was. The conductors varied from No. 14 to 1,000,000 cir. mils and larger (0.064 to 1.156 in. or 1.63 mm. to 29.4 mm. in diameter); the wall of insulation from 3/64 in. (1.19 mm.) to 7/64 in. (2.78 mm.), (0.469 to 0.109 in.). If the 3/64 in. (1.19 mm.) wall of insulation on the No. 14 would stand 1500 volts, it should surely stand much more than this on the 1,000,000 cir. mil. It would therefore be possible for the 1,000,000-cir. mil cable to meet this test even were the wall of insulation defective or actually less than 3/64 in. (1.19 mm.) in places, whereas the main object of the voltage test is to break down any such faults.

The 1911 Code specifications for 0 to 600 volts have, in part, remedied this defect by calling for a test of the 1,000,000 cir. mil at 3500 volts, but at the higher voltages they still hold to 2½ times the working pressure. The specifications of some of the largest buyers in the country today are equally inconsistent.

This is a lamentable condition. It allows too much variation in the dielectric strength of the insulating materials. Some of this variation may be due to ignorance, and some may be intentional. When a cable is tested at only one-half the voltage to which it should be subjected, there results in many instances a carelessness in its manufacture. The writers believe that too little has thus far been accomplished in the line of the standardization of cable testing, when compared with other branches of engineering.

The following tests, in Tables II and III, are recommended for high- and medium-voltage cables, respectively. Table IV, on

TABLE II

RECOMMENDED VOLTAGE TESTS FOR HIGH-VOLTAGE CABLES.

30 per cent Para Rubber

Wall of insulation (in.)	3/64	2/32	5/64	3/32	7/64	4/32	5/32	6/32	7/32	8/32
550,000 cir. mil and larger					14,000	16,000	19,000	22,000	25,000	28,000
500,000 cir. mil to 250,000 cir. mil.					13,500	15,000	18,000	20,500	23,000	26,000
4/0 to 1 B. & S.			11,000	12,000	13,000	14,000	17,000	19,000	21,000	24,000
2 to 4 B. & S.			10,000	11,500	12,500	13,500	16,000	18,000	20,000	22,000
6 B. & S.		8,000	9,500	11,000	12,000	13,000	15,000	17,000	19,000	21,000
8 "	6,000	7,500	9,000	10,000	11,000	12,000	14,000	15,500		
10 "	6,000	7,500	8,000	9,500	10,000	11,000	12,500	13,500		
12 "	5,500	6,500	7,500	8,500	9,000	10,000	11,000	12,000		
14 "	5,000	6,000	7,000	7,500	8,000	9,000	10,000	11,000		

the other hand, is the specification as called for by a purchaser for the cables listed in Table III. It will be seen that the testing pressure recommended is from 1½ to 2½ times that called for by the purchaser. As far as working pressure is concerned, the factor of safety demanded by the purchaser in Table IV is, without doubt, sufficient. Yet the tests called for by this table would not begin to show up any but the most serious defects in the insulation of the respective cables.

The *A. R. E. E. committee on "Wire and Cable Specifications" has taken the most important step thus far in the standardization of voltage tests for cables, in its recent recommendations for tests on rubber, cambric and paper insulation.

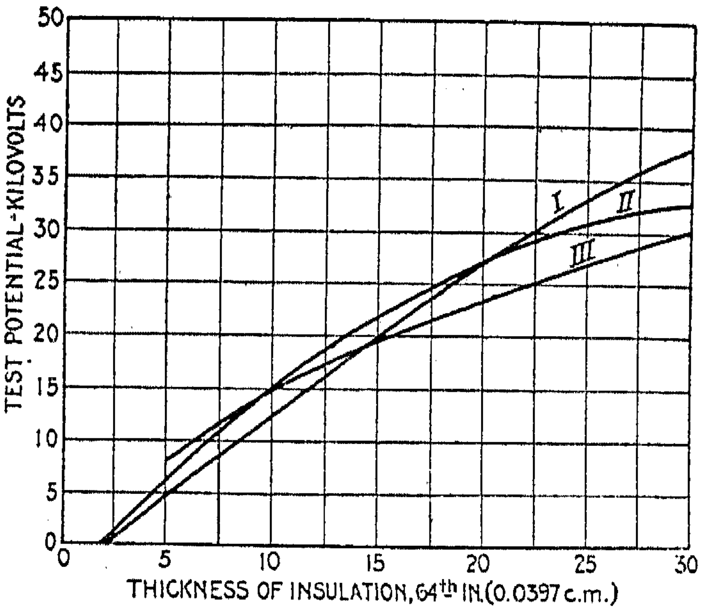

FIG. 4—POTENTIAL TESTS ON CONDUCTORS, RECOMMENDED BY A. R. E. E. No. 1 TO No. 4/0 A. W. G.

I. Paper or varnished cambric.
II. Rubber.
III. $155\, d \log_{10} D/d$ for No. 1 A.W.G.

From Fig. 3 it will be noted that there is but a relatively small difference in the values of $d \log_{10} \frac{D}{d}$ for diameters corresponding to No. 1 and No. 4/0 B. & S. gage, consequently one set of values covering these ranges has been recommended, and is plotted in Fig. 4.

Curve I is recommended for paper and varnished cambric, curve II for rubber, and curve III is the value of $K\, d \log_{10} \frac{D}{d}$ when $K = 155$ and d and D are given in mils. Up to a 20/64-in. (7.95-mm.) wall the paper and cambric are rated at a lower working pressure than the rubber, for mechanical reasons, but above this they should test even better than the rubber.

OVER-STRESSING CABLES

Much has been said in the past relative to unduly severe testing conditions in that the insulation, initially sound mechanically, becomes stressed beyond the electric elastic limit when tested. Although the short duration of the test may not develop any faults, the cable is nevertheless permanently injured, hence less able to withstand the shocks incidental to service conditions. This may be the case, but fortunately the insulation resistance

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*Association of Railway Electrical Engineers.

TABLE III

Recommended Voltage Tests for Low-Voltage Cables.

INSULATED WITH LOW-TENSION RUBBER COMPOUND. VOLTAGE TEST AT FACTORY, FIVE MINUTES AS PER TABLE; VOLTAGE TEST AFTER INSTALLATION, 30 MINUTES AT 50 PER CENT OF TABLE VALUE.

Size conductor	Minimum thickness insulation, inches.	Test pressure, volts.
Stranded		
1,000,000 cir. mils	4/32	10,000
750,000 "	4/32	10,000
500,000 "	4/32	9,000
350,000 "	4/32	9,000
4/0 A. W. G.	3/32	7,000
2/0 "	3/32	6,500
1/0 "	3/32	6,500
2 "	3/32	6,000
Solid		
4 A. W. G.	3/32	5,500
6 "	3/32	5,500
8 "	3/32	5,000
10 "	3/32	4,500
12 "	3/32	4,000
14 "	5/64	3,500
14 (3) " conductor	5/64	3,500

TABLE IV

Voltage Tests as Specified by a Purchaser.

TESTS ON CABLES INSULATED WITH LOW-TENSION RUBBER COMPOUND. VOLTAGE TEST AT FACTORY, FIVE MINUTES AS PER TABLE; VOLTAGE TEST AFTER INSTALLATION, 30 MINUTES AT 50 PER CENT OF TABLE VALUE

Size	Strands.	Wall.	Volts working pressure	Volts test pressure
Stranded				
1,000,000 cir. mils.	61	4/32	1000	4000
750,000 "	61	4/32	"	4000
500,000 "	37	4/32	"	4000
350,000 "	37	4/32	"	3000
4/0 A. W. G.	19	3/32	"	3000
2/0 "	19	3/32	"	3000
1/0 "	19	3/32	"	3000
2 "	7	3/32	"	3000
Solid				
4 A. W G.		3/32	1000	3000
6 "		3/32	"	3000
8 "		3/32	"	3000
10 "		3/32	"	3000
12 "		3/32	"	3000
14 "		5/64	"	2000
14 "	3-Cond.	5/64 (no belt)	"	2000

he electrostatic capacity enable us to determine the degree
ich the insulation has been over-stressed.
mediately after the stress is applied, the insulation resist-
measured with direct current, may drop considerably
its initial value as obtained a few moments previous to the
ation of voltage. This change may be as great as 50 per
If further readings of insulation resistance are taken, they
how a gradual increase and will approach their initial value

TABLE V

Wires Showing Results of Stress.

Megohms in 1000 ft.

Feet	Before voltage	2500 volts 1 min.	5000 volts 1 min.	After 2 hours	5000 volts 5 min.	After 2 hours	
1562	14,500	14,500	7,500	11,500			
1547	22,000	22,000	16,000	18,000			
3150	7,500	7,500	6,000	7,000	5,000	5,000	
1740	15,000	15,000	6,500	10,000	750	2,500	
2402	15,000	15,000	7,500	10,000	2,500	3,500	
						Break-down voltage	Megohms in 1000 ft. after repair. 4000 volts, one min.
3560	4,800				4,620	13,000	4,100
1425	3,500				3,440	12,000	4,470
2350	9,000				9,015	15,000	8,425
2750	7,660				7,660	15,000	9,150
2400	2,950				2,740	7,500	2,810

cable has not been over-stressed, whereas, if it has been
ressed, the resistance recovers but little. Care must be
to keep the temperature constant during these tests, for
ion has a very large resistance temperature coefficient.
V shows some typical data taken from tests made on long
of wire as they were passing through the testing room.
insulation resistances in tests (1) and (2) were affected
rably after the 5000-volt one-minute test, but practically
ed after two hours. It is possible that they would have

completely regained their initial resistance if allowed sufficient time.

Tests (3), (4) and (5) were first made under the same conditions and, except in the case of (3), the recovery was much poorer than in the former cases. They were then subjected to 5000 volts for five minutes, with a noticeable reduction in the resistance of (3) and a very large and permanent reduction in that of (4) and (5). These last two were permanently injured.

In tests (6) to (10) inclusive, there was no marked decrease in resistance after the 5000-volt test, so they were broken down, repaired by patching the faults, tested at 4000 volts for one minute, and the insulation resistance measured again, with the results shown in the table. Tests (7) and (9) gave even better results than the initial resistances, due no doubt to patching a localized fault.

TABLE VI

WIRES SHOWING THE RESULTS OF STRESS.

Microfarads per 1000 ft.

Feet	Before voltage test	After 5000 volts for 1 min.
3150	0 126	0.130
2176	0.146	0.150
2470	0.130	0.134
2925	0.130	0.133
2775	0.120	0.124

Unfortunately, the electrostatic capacity of these cables was not measured after every application of voltage, but Table VI shows in a general way the increase of capacity due to stress in the dielectric. For a given stress the change in capacity is much smaller than the change in resistance.

These results show that it is possible to make a rubber compound which is not easily stressed beyond the electric elastic limit, and further, that if a compound is so stressed it is possible by means of the insulation resistance to determine if the test has been too severe.

FACTOR OF SAFETY

It is not the intention of the writers to tell the operating engineers what should be the factor of safety in a cable system. Great fear has been expressed now and then, that engineers, knowing that cables will stand these high-voltage tests, will be tempted to use them on higher working pressures than they should. In this connection it is well to bear in mind that a factor of $2\frac{1}{2}$ times the working pressure is not applicable to all conditions.

(1) *In two systems of the same kilowatt capacity the cables on that system having the lower voltage should have the greater factor of safety.* This is because the surge voltage on the lower-voltage system will be greater because of the greater current, and the maximum possible rise in voltage is $e = i\sqrt{\frac{L}{C}}$, where i is the amperes current transient, and L and C the system inductance and capacity, expressed in henrys and farads respectively.

(2) *In two systems having the same voltage, those cables operating on the system having the greater kilowatt capacity should have the greater factor of safety.* The reason for this is obvious. As has been frequently observed, transients that are practically unimportant in a small system become dangerous if allowed to take place in a large system. The writers have in mind a case where 2300-volt distributing cables, when connected to a relatively small plant, gave practically no trouble, but later, when this smaller system received its energy from a large transmission network, these same cables, though *normally* operating at the same voltage as before, gave so much trouble that they had to be replaced by cables better suited to the conditions.

METHOD OF TESTING

The voltage test can be applied to wires and cables in several different ways; by submerging the cables in water; testing them against a metallic covering on the outside such as a lead sheath or tin foil; and testing one wire against another when there is more than one wire in the cable. The submersion test is the most severe, as the water makes very close contact with the outside of the cable, regardless of any surface irregularities that may be present. The water also has a tendency to penetrate into any foreign substance that may be in the insulating material, provided this substance has any affinity for water.

All of these tests may be, and generally are, made on rubber insulated cables. The cambric cables to be braided are generally submerged before and after braiding; cambric cables to be lead-covered are not submerged, as considerable trouble in drying them is experienced, and as they are to be tested after the lead covering has been applied, the submersion test is not necessary. Paper cables are not submerged, and all tests are made after leading.

The voltage test, as applied to cables, is practically the same whether it is made submerged, against the lead, or against the contiguous wires, the object being to break down any weakness that may exist in the insulation. How much pressure, and for how long it shall be applied, are questions that have long been the subject of much discussion.

For several reasons, it is necessary to apply the voltage test to the finished cable and not to a short sample. (1) It is desirable to break down any weak places that may occur in the cable, it being quite impossible to avoid entirely such places in manufacture; (2) to satisfy inspectors and purchasers that the cable meets specifications as regards dielectric strength; (3) to obtain data and information as to the dielectric strength of the material; (4) constants obtained in laboratories from tests of short lengths are not applicable to commercial lengths and are usually misleading.

TESTING APPARATUS*

Recommendations have appeared at different times regarding the type of generator and transformer that it is advisable to use for testing purposes, and the consensus of opinion seems to be that a smooth-core generator with field control, and a variable-ratio transformer, are most satisfactory. As will be shown later, it is doubtful if the generator of ordinary design can maintain its wave form under the severe conditions imposed by cable testing.

Where cables of some length are to be tested, a frequency of 25 cycles is preferable to one of 60 cycles, for the necessary generator and transformer capacities are practically proportional to the frequency, and according to the best information the writers can obtain there is no appreciable difference in severity of cable tests whether made at 25 or 60 cycles.

In the following tests, made in the testing laboratory of a wire manufacturer, the generator used was a motor-driven 25-kv-a., 220-volt, four-pole, 25-cycle, single-phase alternator, having 10 slots per pole, and a conductor belt $\frac{5}{8}$ the pole pitch. The transformer capacity was 50 kv-a., 220-50,000 volts. The secondary consisted of four separate 12,500-volt coils, capable of being con-

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***High-Tension Testing of Insulating Materials*, A. B. Hendricks, TRANS. A. I. E. E., 1911, Vol. XXX, part I, page 167.

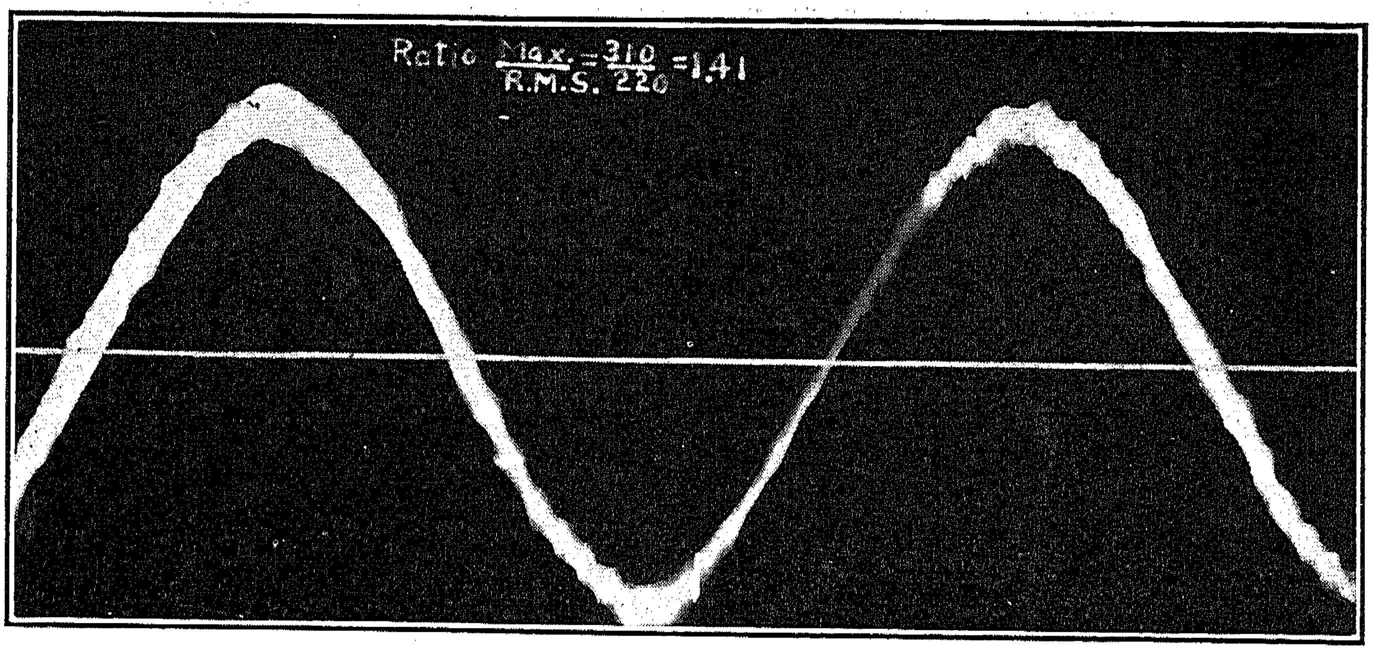

FIG. 5 [MIDDLETON AND DAWES]

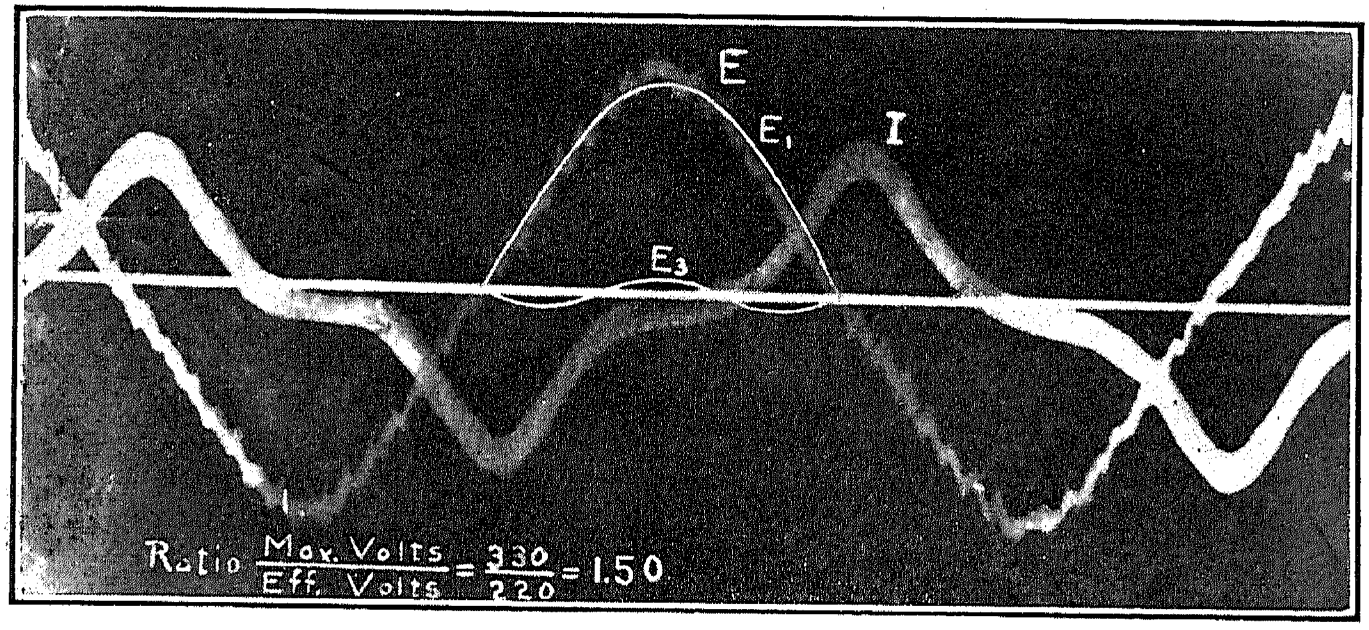

FIG. 6 [MIDDLETON AND DAWES]

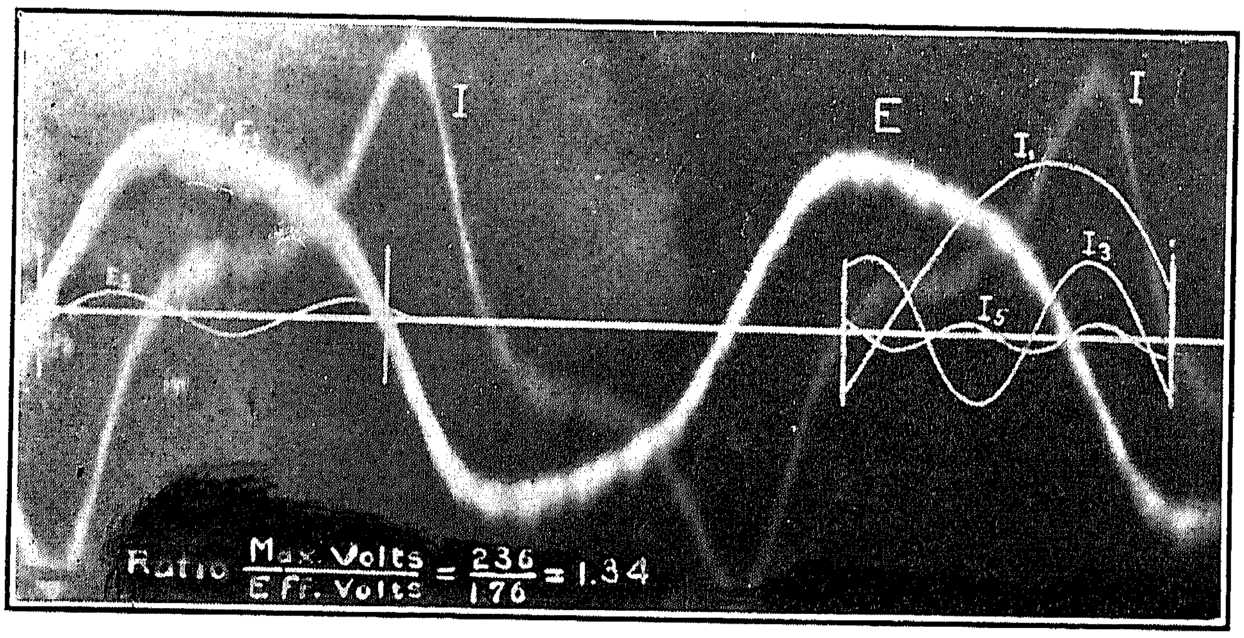

FIG. 7 [MIDDLETON AND DAWES]

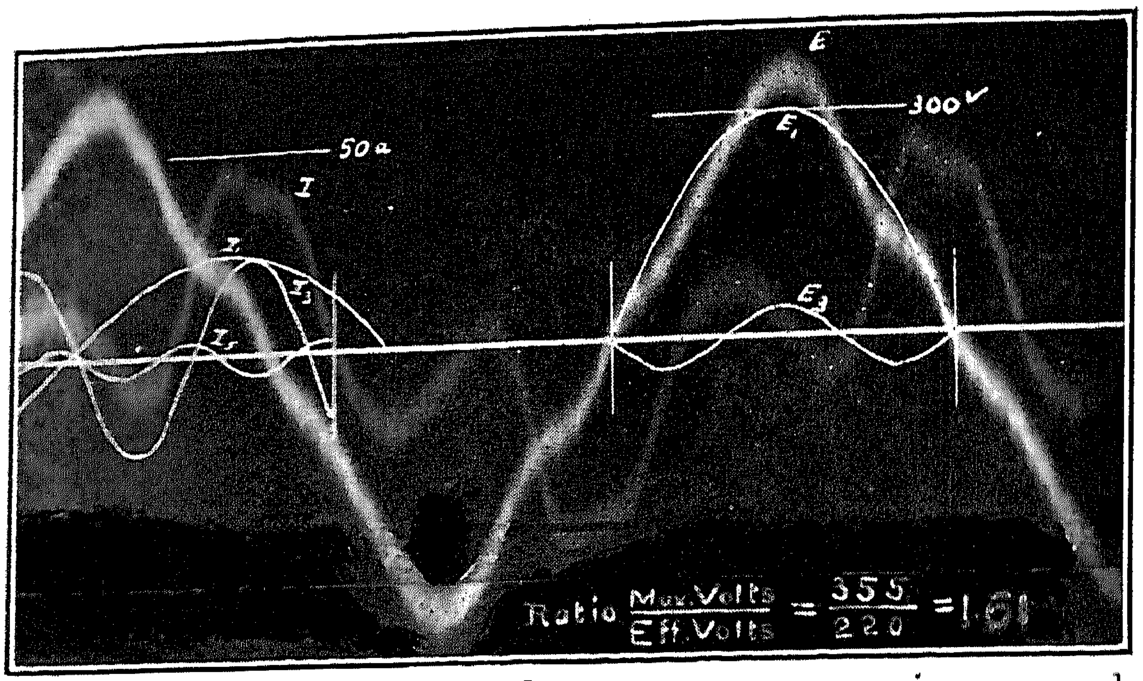

FIG. 8 [MIDDLETON AND DAWES]

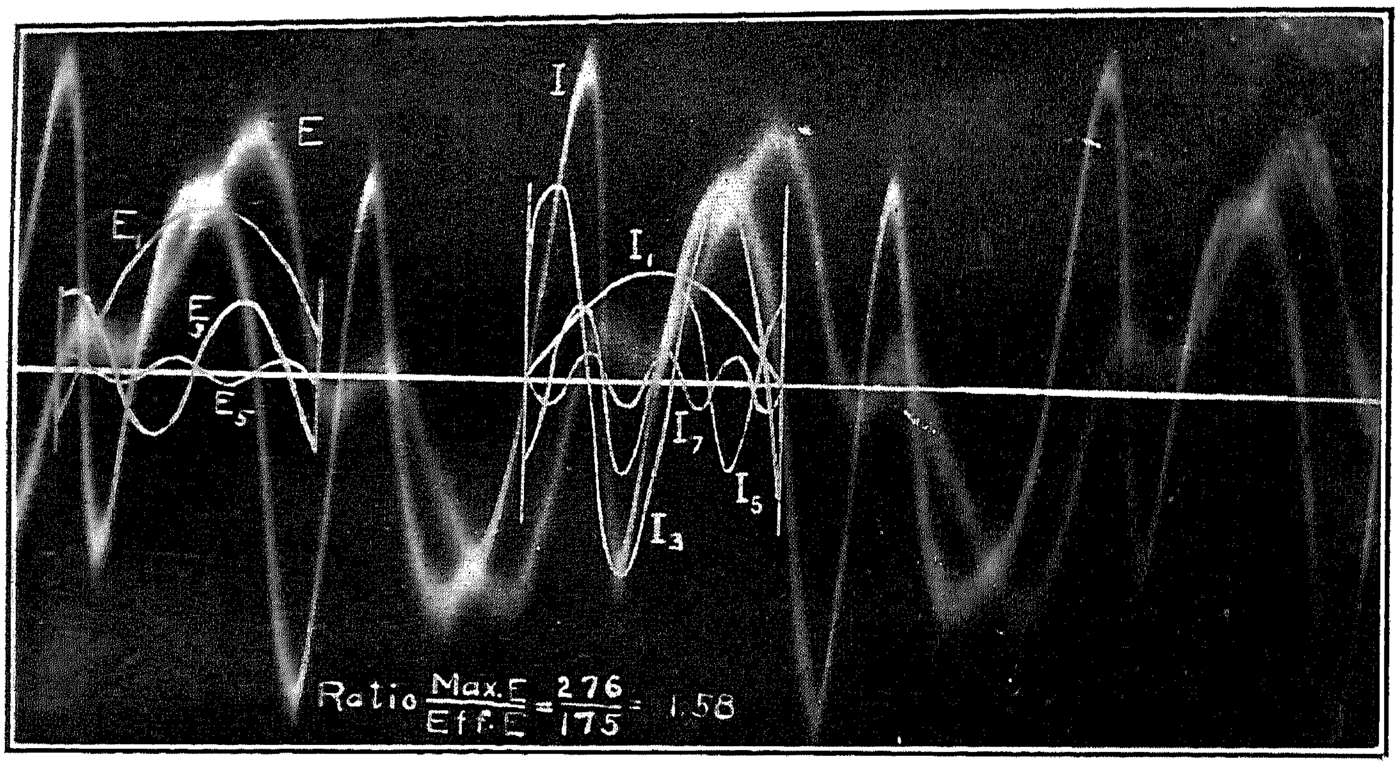

FIG. 9 [MIDDLETON AND DAWES]

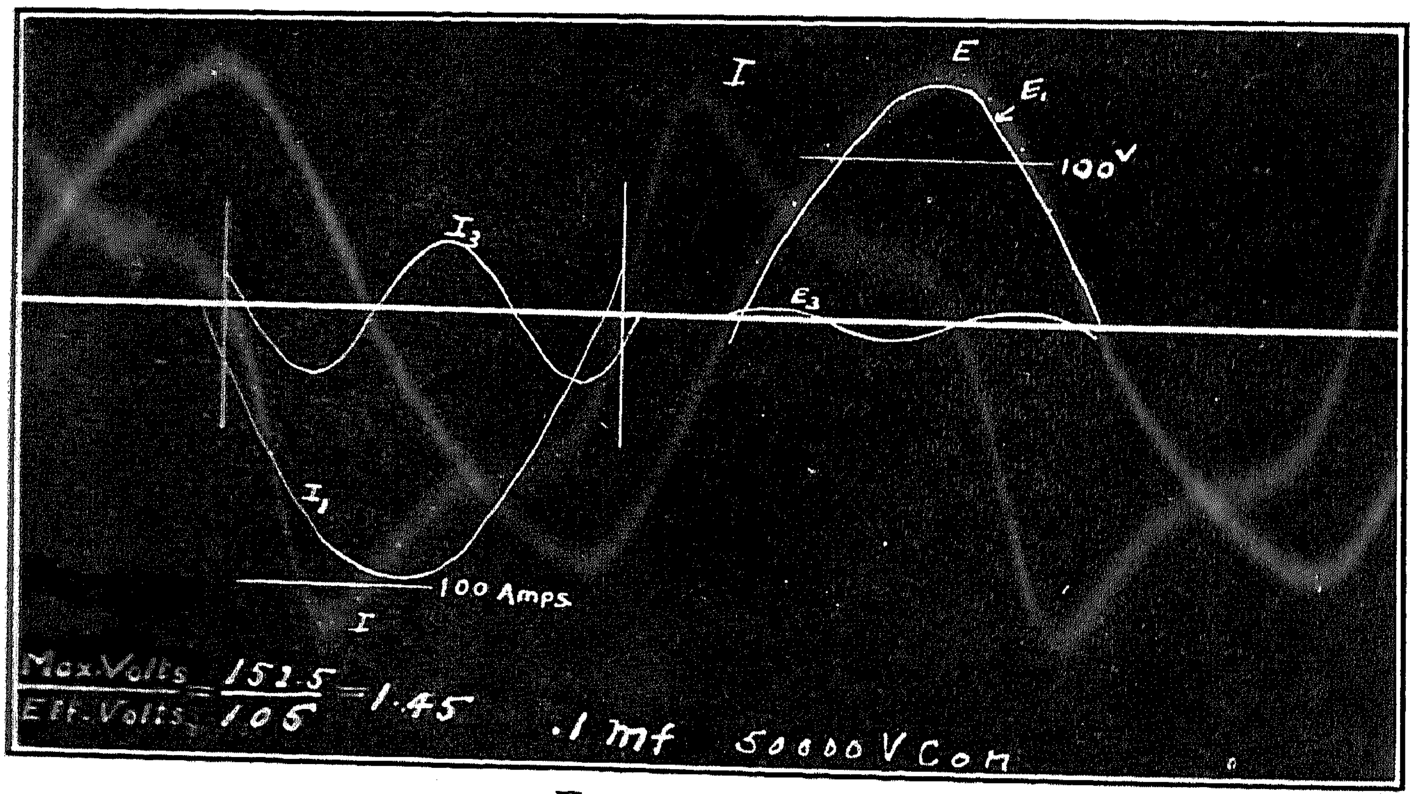

FIG. 12 [MIDDLETON AND DAWES]

nected either in parallel, in series-parallel, or in series. The high-tension winding had a total of 12,512 turns, and the low-tension 55 turns. The reactance voltage was about 6 per cent.

Fig. 5 shows the generator voltage on open circuit, and except for the tooth harmonics, the e.m.f. wave is practically sinusoidal. For testing purposes, this wave is perfectly satisfactory if it could be maintained under all load conditions. In Fig. 6 is shown the generator voltage wave taken at 220 volts when the transformer is connected, and also the exciting current wave of the transformer.

This transformer exciting current is about 17 per cent of the rated load current of the transformer, but is 34 per cent of the rated load current of the generator. This is rather high, and further, Fig. 6 and other experiments showed that the transformer iron was being operated at unusually high saturation. It might well be argued that a large transformer magnetizing current is desirable, as it tends to offset the leading component of cable charging current, but it should be remembered that beyond a certain core density the additional exciting current is made up almost entirely of harmonics which do not neutralize the fundamental. Experience has shown this to be undesirable for other reasons. Examination of the current wave in Fig. 6 shows that the transformer takes a pronounced third harmonic current, and this current reacting on the generator flux tends to start wave distortion, producing a third harmonic in the e.m.f. wave as shown. If a cable, like most other electrical apparatus, took a comparatively small charging current, most of the following difficulties, due to wave distortion, would disappear.

Figs. 7, 8 and 9 show various voltage waves actually obtained under different conditions of test. The voltages on the cables, given in connection with all the following oscillograms, are according to the ratio of transformation, hence, are not strictly correct. In actual practise this voltage is determined directly from the high-tension side by means of a potential transformer.

The reasons for this distortion are obvious. The generator may have, inherently, a sine wave voltage, but the transformer exciting current has a prominent third harmonic. This current and the single-phase pulsating armature reaction produced on the flux wave, will usually introduce harmonics in the voltage wave as shown in Fig. 6. This wave is communicated to the transformer secondary where the cable intensifies it in its charging current, and it is reflected back in the generator current, and increased wave distortion results. These reactions are cumulative and will continue to increase until counter-reactions set up in the magnetic and electric circuits become sufficiently great to balance them. Generator saturation, generator and transformer series leakage reactance and the phase relations of the harmonics may tend to counteract distortion. The value of series reactance may be such as to produce resonance for one harmonic and not the others.

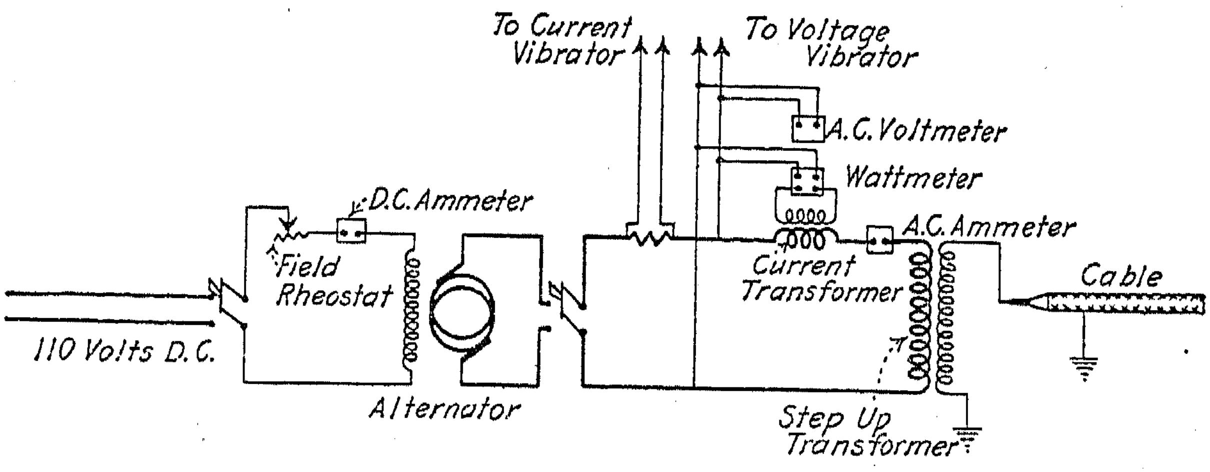

FIG. 10—DIAGRAM OF CONNECTIONS

The generator may be represented by a coil that is a source of voltage and having reactance and resistance; the transformer may be replaced by a shunt impedance, of a value equal to the open-circuit impedance of the transformer, and by two series impedances, one representing the equivalent resistance and leakage reactance of the primary side, and the other the impedance of the secondary reduced to the primary side; the cable represents a condenser referred to the primary side and having a very high effective resistance. Fig. 11 shows this condition.

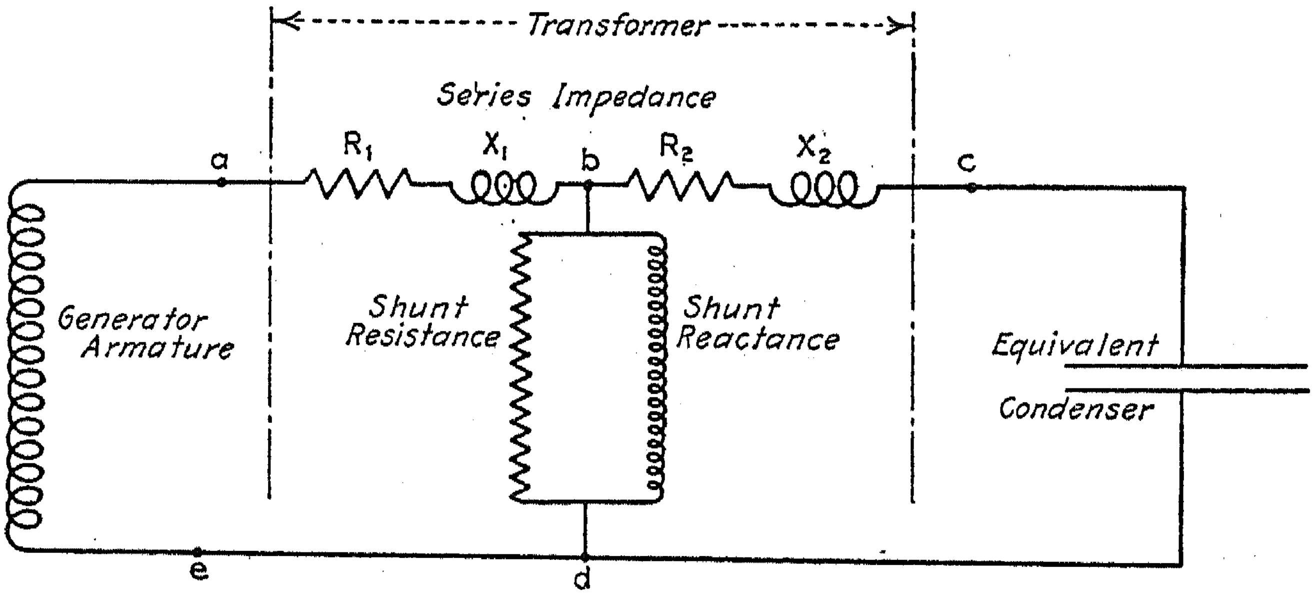

FIG. 11—EQUIVALENT CIRCUIT DIAGRAM

The shunt impedance *b d* has a decided effect on the generator wave form, in that its current wave, especially at the higher voltages, is mostly made up of harmonics, and these, reacting on the

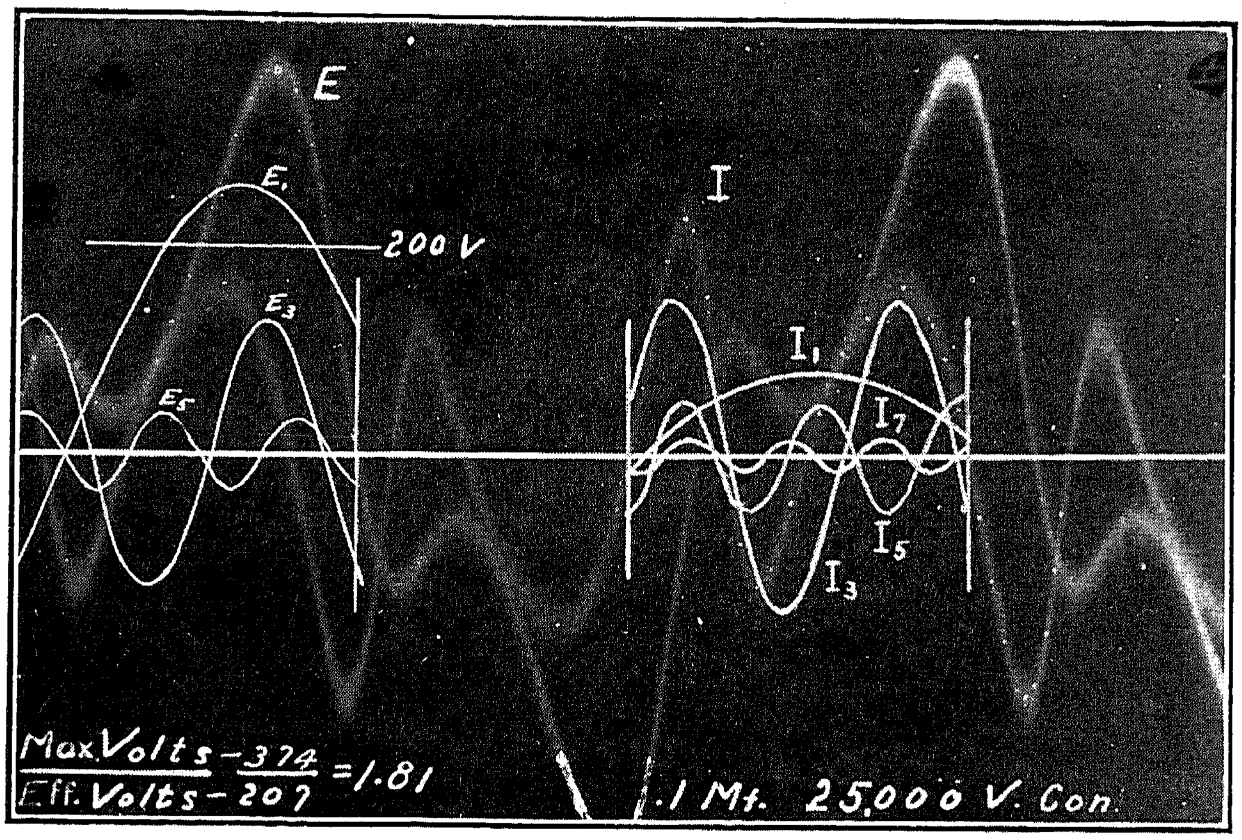

FIG. 13 [MIDDLETON AND DAWES]

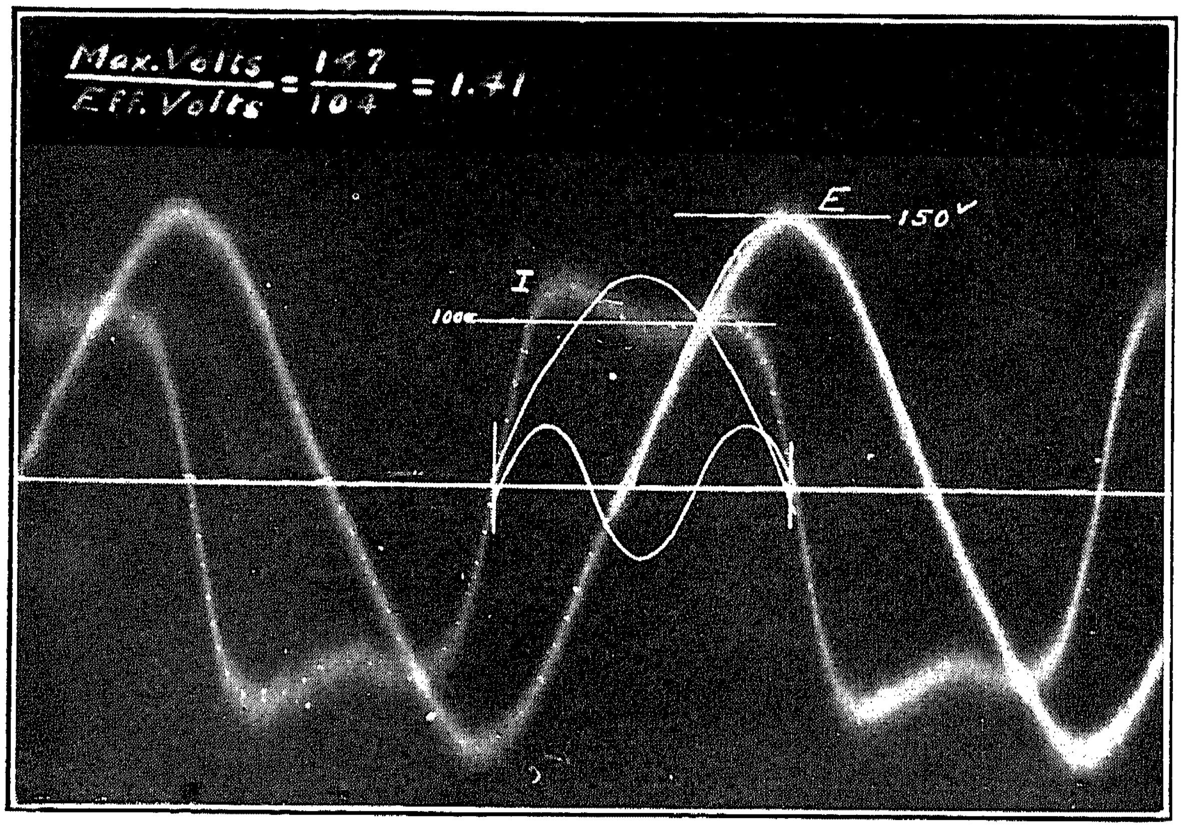

FIG. 14 [MIDDLETON AND DAWES]

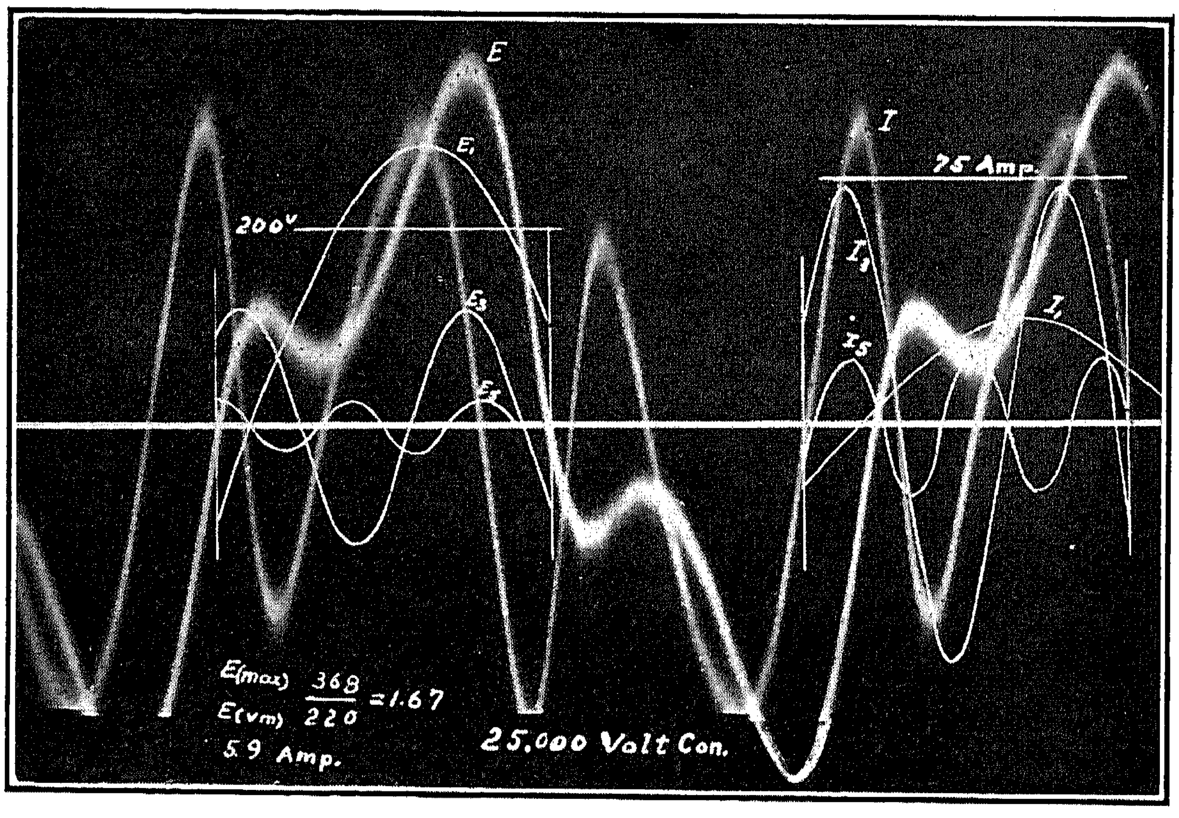

FIG. 15 [MIDDLETON AND DAWES]

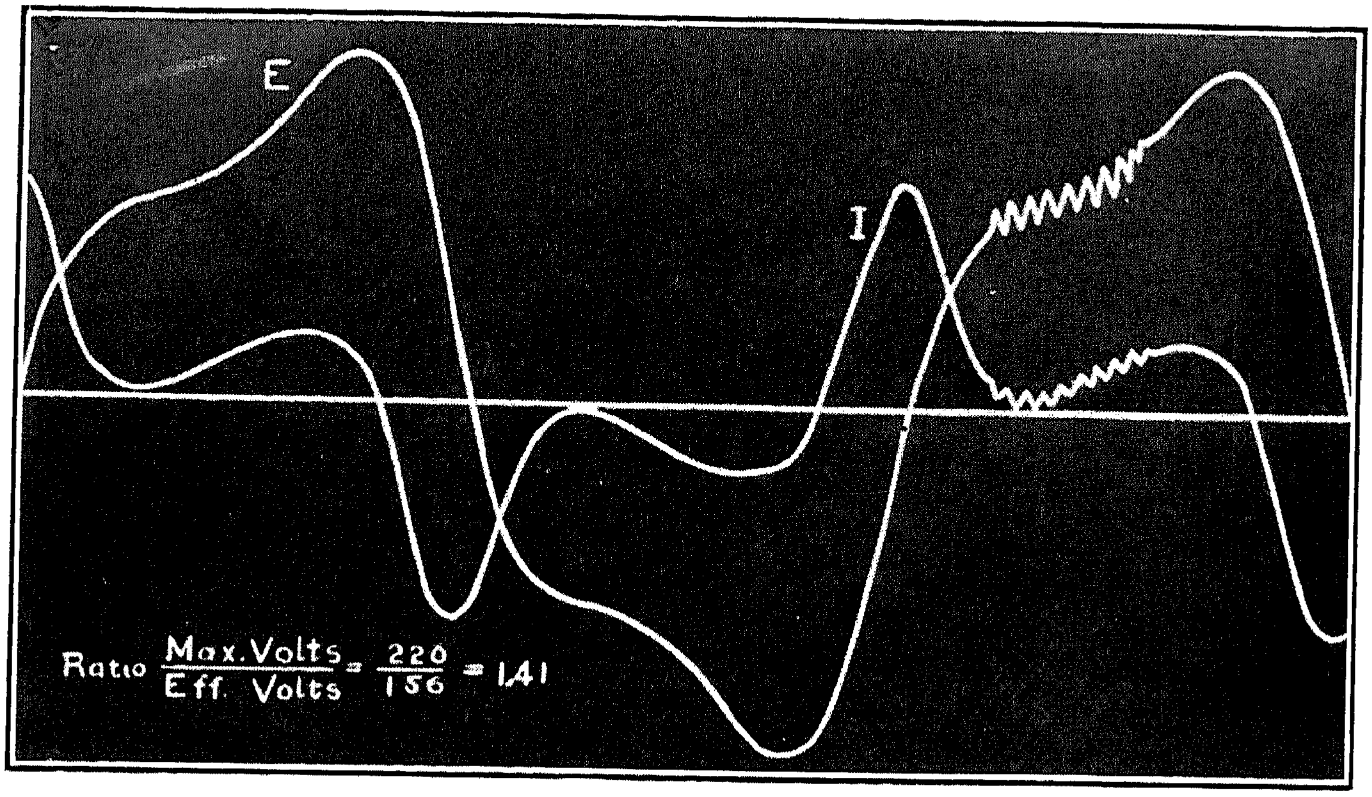

FIG. 16 A [MIDDLETON AND DAWES]

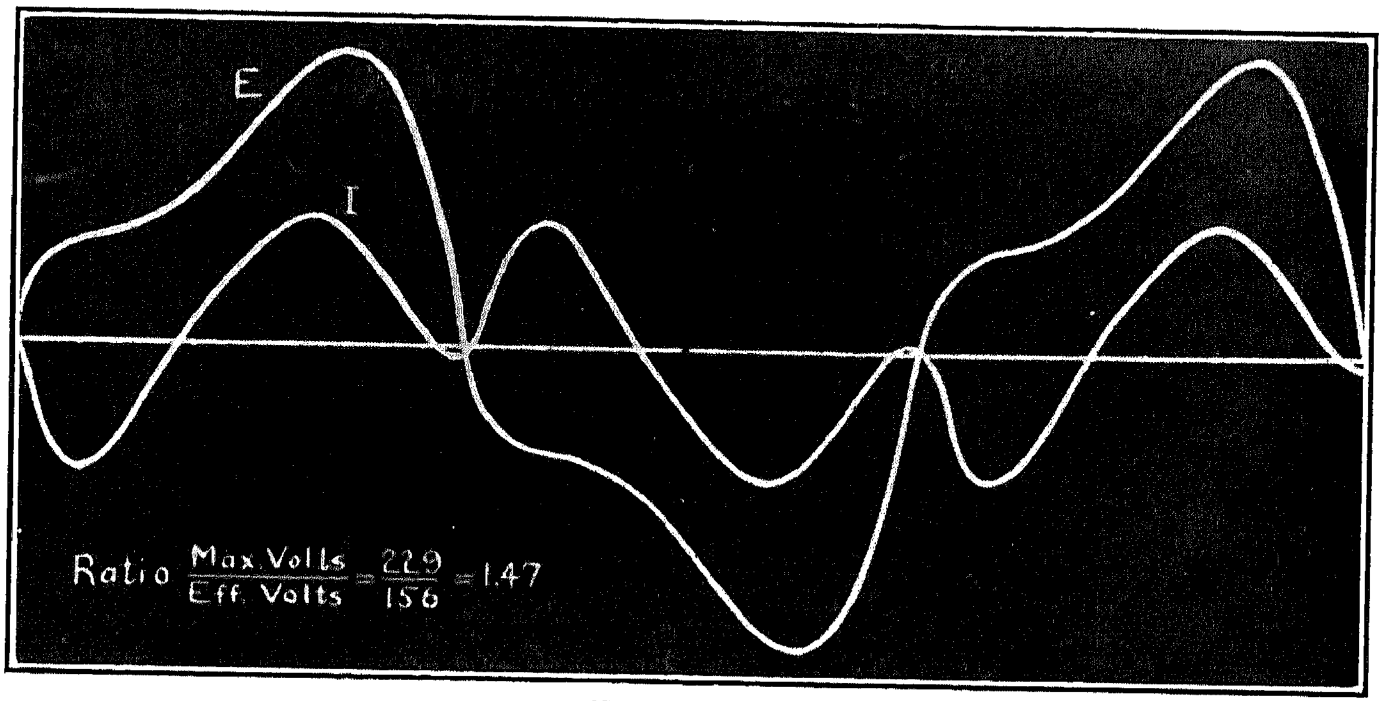

FIG. 16 B [MIDDLETON AND DAWES]

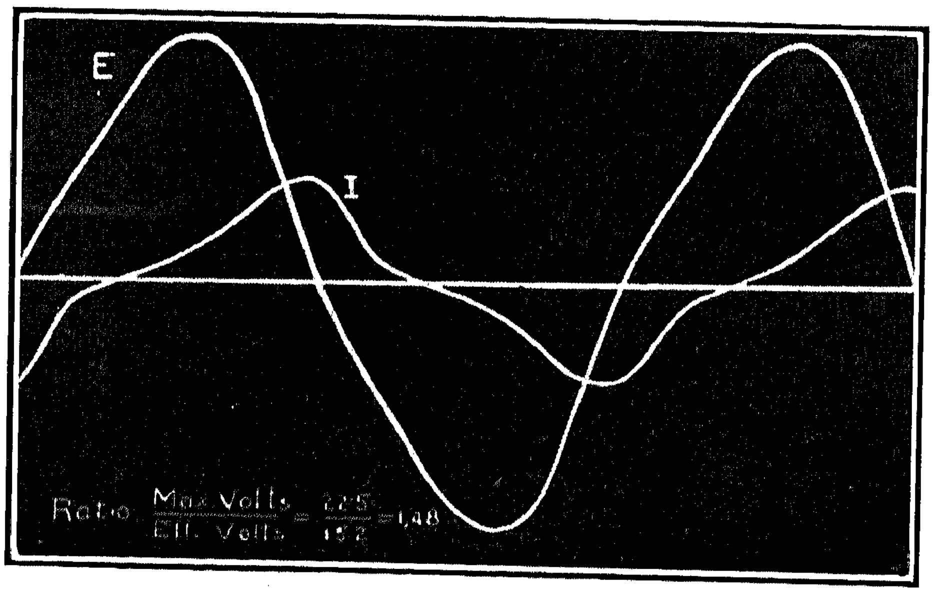

FIG. 16 C [MIDDLETON AND DAWES]

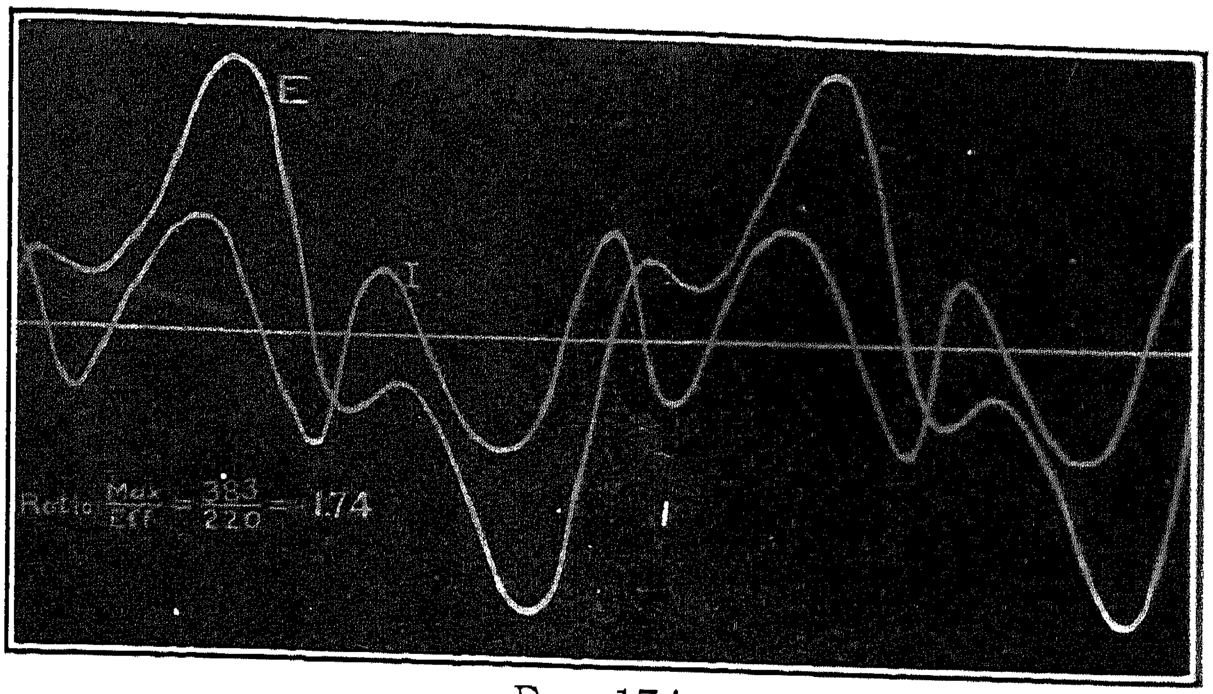

FIG. 17A [MIDDLETON AND DAWES]

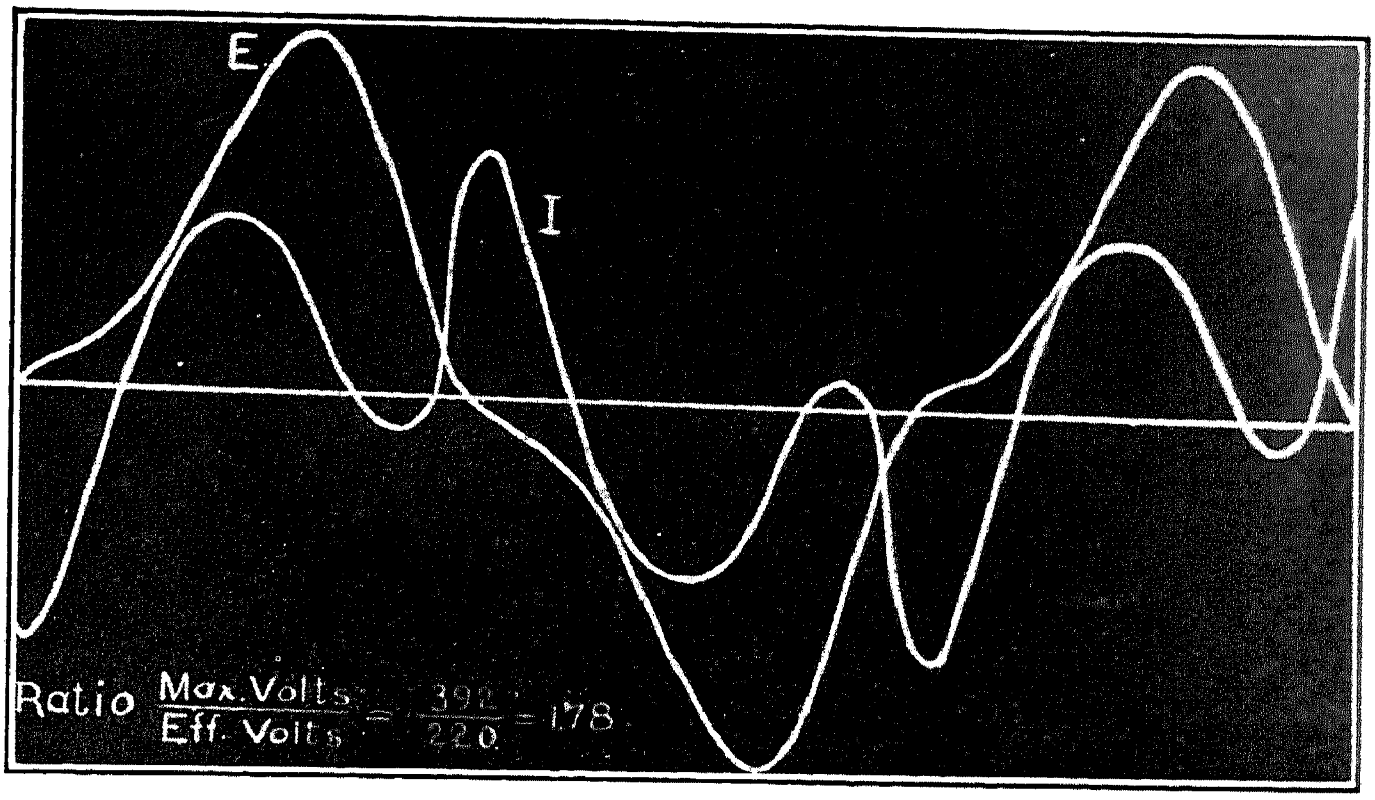

FIG. 17B [MIDDLETON AND DAWES]

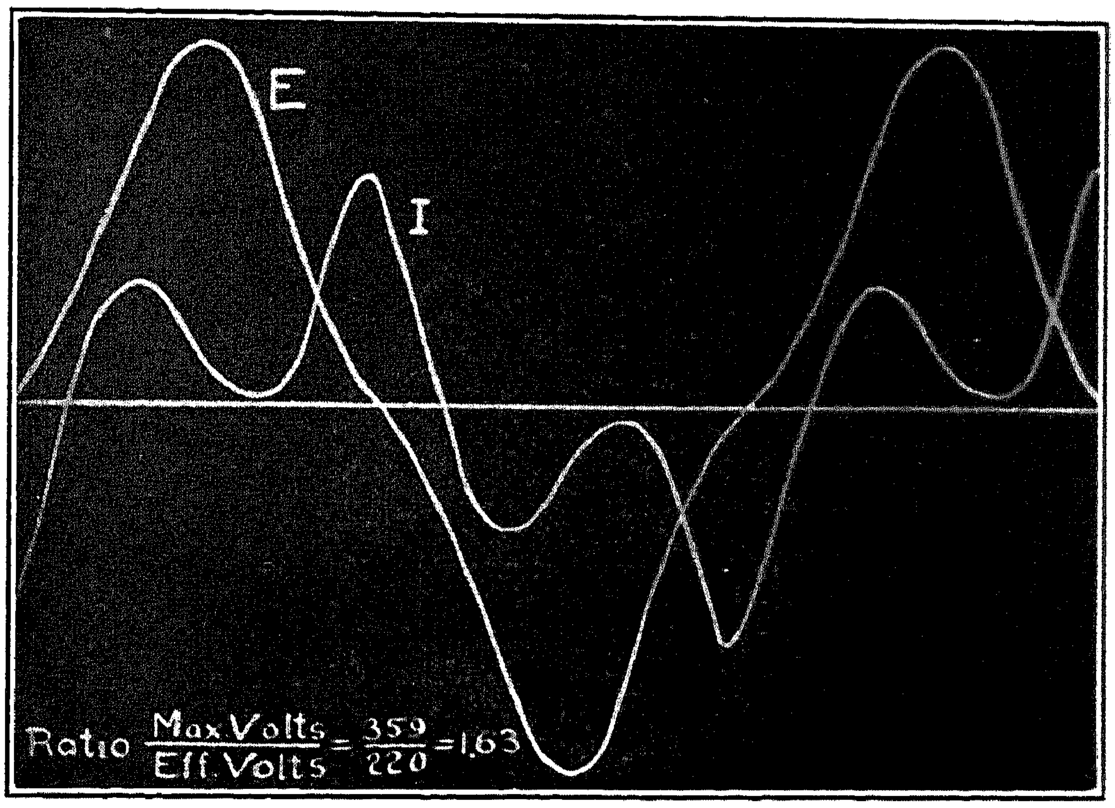

FIG. 17C [MIDDLETON AND DAWES]

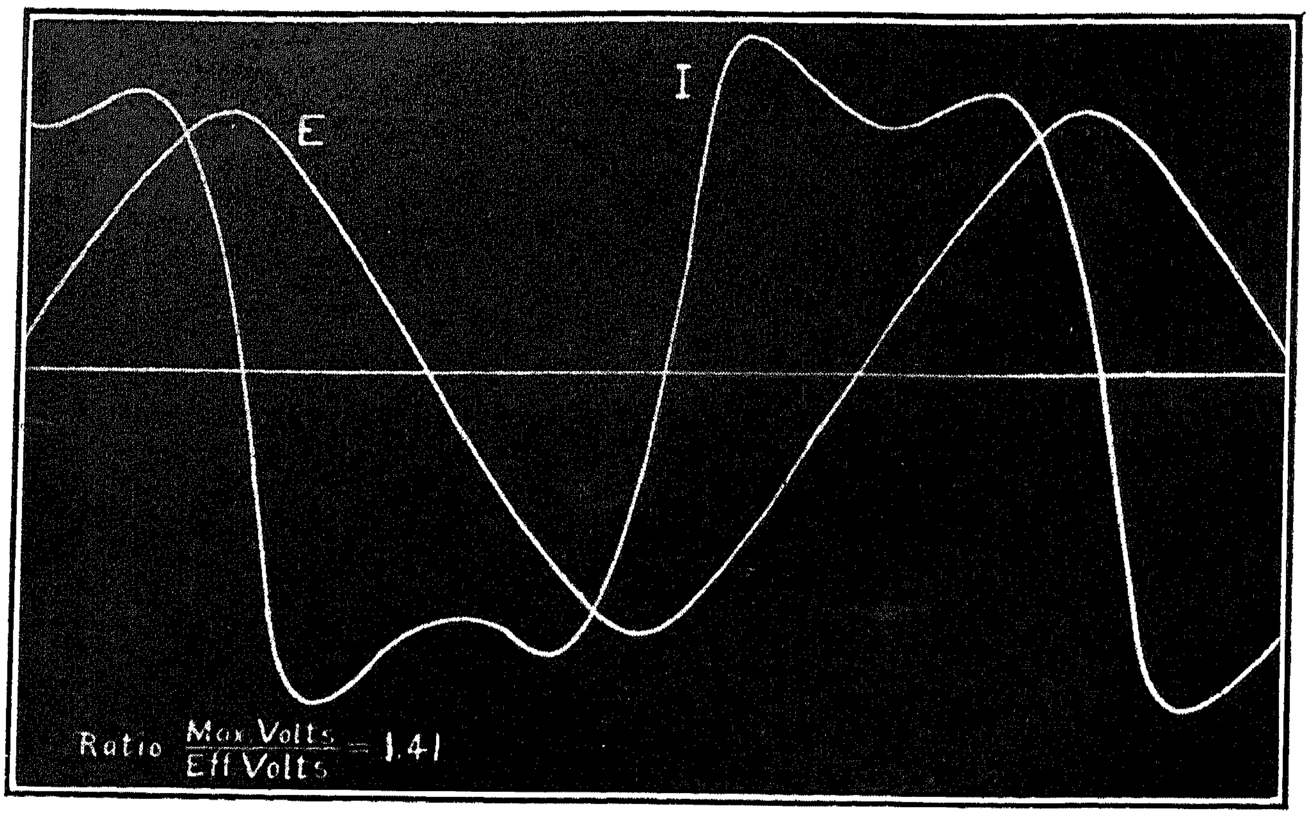

FIG 18A [MIDDLETON AND DAWES]

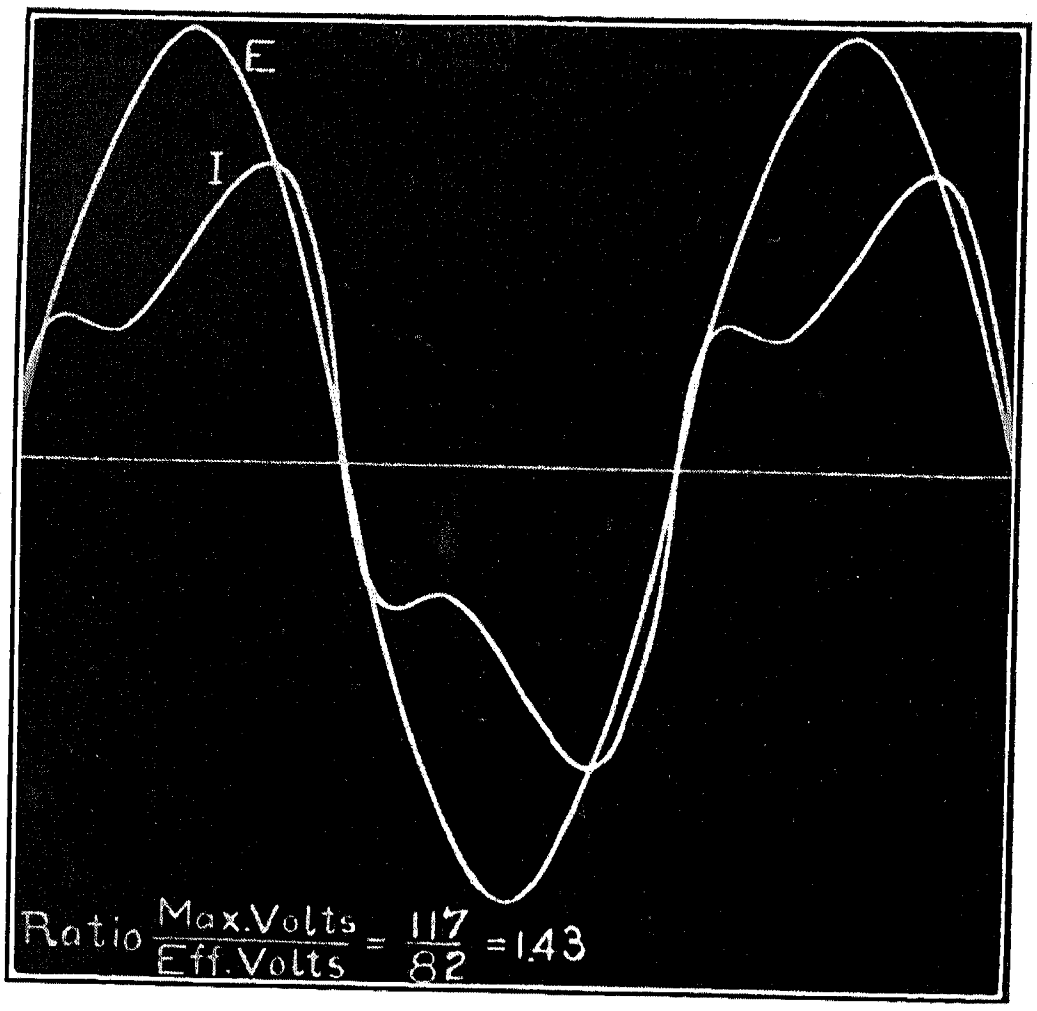

FIG. 18B [MIDDLETON AND DAWES]

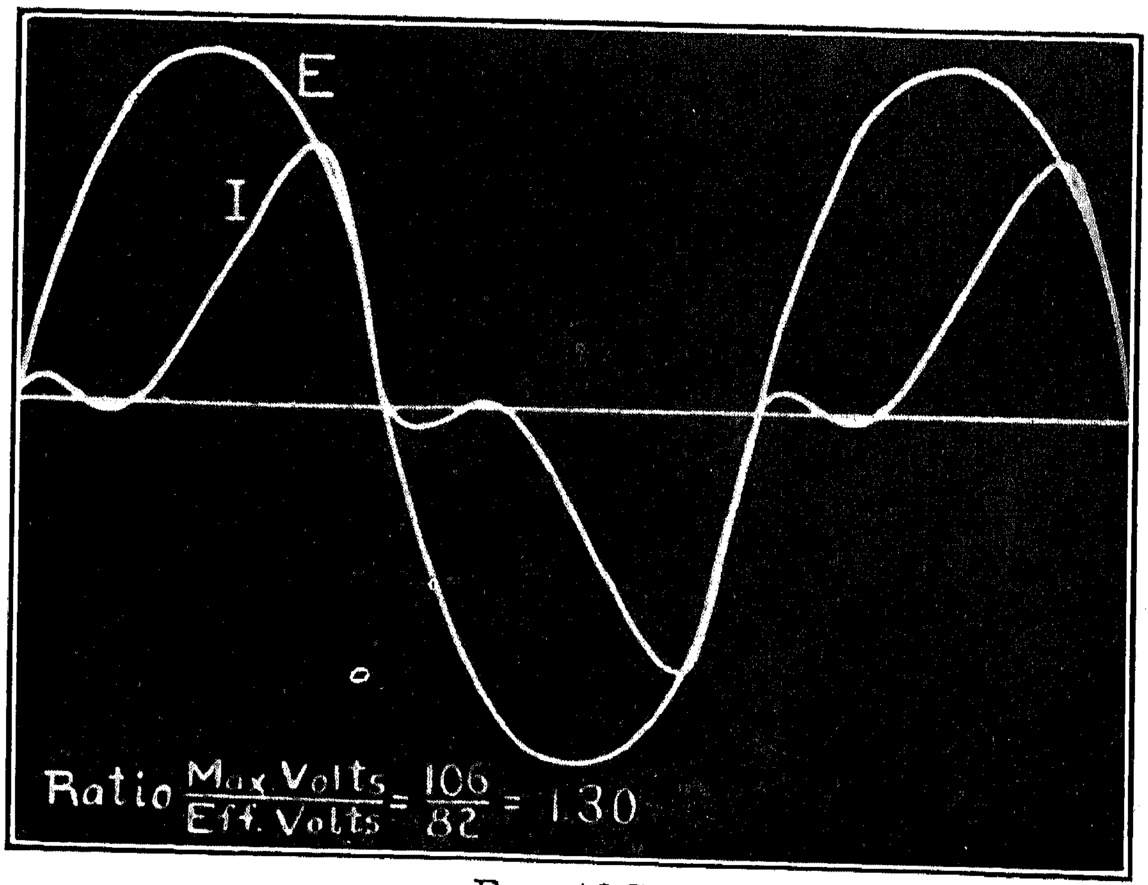

FIG. 18C. [MIDDLETON AND DAWES]

generator flux, are responsible for the initial distortion to which reference has been already made. The series circuit *a b c d e*, consisting of the transformer primary and secondary resistances and leakage reactances and the condenser, all in series with the generator armature, exerts some influence on the generator wave form. The magnitude and shape of the generator current wave may be dependent on the relation of inductance to capacity in this circuit. Therefore, harmonics may be intensified or diminished, depending on their frequency, on the transformer inductance and the cable capacity. These effects are illustrated in Figs. 12 to 15 inclusive.

The oscillograms shown in Figs. 12 and 13 were taken when a cable having a capacity of 0.1 microfarad was connected to the transformer secondary, and those shown in Figs. 14 and 15 were taken with another cable having a capacity of 0.13 microfarad, connected to the transformer secondary. Two tests were made with each cable; one in which all four of the transformer secondary coils were connected in series (50,000-volt) connection, the other in which the series-parallel (25,000-volt) connection was used. In order to compensate for the change in transformer ratio so that the effective voltage on the cable should remain approximately unchanged, the generator voltage was practically doubled when the change was made from the 50,000-volt to the 25,000-volt connection.

Figs. 12 and 14 show the results obtained with the 50,000-volt connection, and in each case the e.m.f. wave is very nearly sinusoidal, and no appreciable harmonics above the third, appear in the current wave. In each of these cases the generator was operated at low saturation, a condition in which it would be less able successfully to oppose severe reactions on the flux wave. The natural frequency of the transformer and cable circuit in the case of Fig. 12 is 110 cycles, and of Fig. 14, 96.6 cycles. The shunt circuit *b d*, owing to the variable nature of its inductance, would be difficult to take into consideration, except in a very general way, and was consequently neglected in this frequency determination.

In Figs. 13 and 15, the approximate sinusoidal e.m.f. waves shown in Figs. 12 and 14 are distorted, containing fair-size fifth harmonics, and third harmonics about 50 per cent of the fundamental. In each case the current wave is even more distorted than the e.m.f. wave, showing a seventh harmonic, a fifth equal in magnitude to the fundamental and a thirdabout twice as great as the fundamental. In these cases, the natural frequency of the circuit was 215 and 192 cycles respectively.

Thus in each case, with the same generator, the same transformer, the same frequency and the same cable, an approximate sine wave is converted into a complex wave by simply changing the transformer ratio and the generator voltage. These phenomena cannot be explained on the basis of a resonant series circuit, for the best wave shapes were obtained when the circuit constants were more conducive to the flow of the troublesome third and fifth harmonics. However, in these two latter cases the transformer exciting current contains harmonics of very appreciable magnitude as shown in Fig. 6, and in the writers' opinion, these harmonics are practically responsible for the results that were obtained.

It might also be added, referring to Fig. 11, that in the circuit *a b c d*, the resistance is very small, thus offering excellent opportunities for oscillations to take place during the transient or building-up condition. Great care must be exercised in raising and lowering the voltage, as the possibility of building up an abnormal potential across the cable is always present, and this may result in a puncture.

Specific illustrations of this have come to the writers' attention on several occasions. When the voltage across a cable was being gradually raised, the spark-gap, connected in parallel, would discharge light sparks, momentarily, when the switchboard voltmeter indicated that the potential across the gap was only half that at which the gap was set. If the voltage was held constant for an instant, the sparking would discontinue, and the voltage could then be raised cautiously without further disturbance. The fact that the gap was not ruptured showed that a transient rise of voltage occurred, but that there was insufficient energy to cause a dynamic arc.

USE OF REACTANCE

It occurred to the writers that the generator current might be considerably reduced by using a shunt reactance to neutralize the leading component of the cable-charging current, thus securing a better wave form by reducing the ampere load on the generator. This has been tried abroad* and also by the Edison Electric Illuminating Co. of Boston.†

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* *Electrotechnischer Zeitschrift*, Feb. 27, 1908.

† "High-Potential Cable Testing at Boston," by C. L. Kasson, *Electrical World*, Vol. 60, p. 354.

We made nine tests, and in every case the same cable was used, namely 1000 ft. (305 m.) No. 1/0, 7/32 in. (5.56 mm.) wall, rubber insulation, having a capacity of 0.175 microfarad. Three different tests were made at each of three different voltages. At each voltage: first, the oscillogram was taken without the reactance; second, the reactance was adjusted until the line current was a minimum; and third, the reactance was adjusted for the best voltage wave form. The results of these tests are shown in Figs. 16A to 18C inclusive.

The following conclusions are to be drawn from the above tests:

(1) The point of minimum current does not necessarily correspond to the best wave shape.

(2) The best wave shape may occur at an abnormally large value of lagging current.

(3) The wave can not be made sinusoidal in every case.

(4) At the point of minimum current (usually denoting resonance for a parallel circuit) the power factor is below 50 per cent in two cases, and 70 per cent in the third, and the waves are not necessarily in phase.

Further, in Figs. 18A, 18B and 18C, when the generator voltage was low, there was but slight distortion in the e.m.f. wave, which tends to confirm the previous theories as to the effect of the transformer exciting current on the e.m.f. wave.

Thus with a commercial generator and transformer, the e.m.f. wave, by the use of reactance, could not always be made sinusoidal, and when this was accomplished, it was at the expense of greater generator capacity. This is undoubtedly due to the fact that a circuit can be tuned to but one frequency at a time, and when the third harmonic current was neutralized, the reactance allowed a very large fundamental to pass. The power factor is explained by the fact that the harmonic currents in cable tests predominate in the current wave, whereas the voltage is largely fundamental. The harmonics in the current wave contribute no power with respect to the fundamental voltage, yet all add up in quadrature, contributing to the volt-amperes.

These results show that in our particular case, at least, a shunt reactance would be of but very little value in improving the generator wave form, and reducing the volt-ampere load of the generator.

SINE-WAVE GENERATOR

As a result of our tests, the wire manufacturer came to the conclusion that a generator of the ordinary design was wholly unsuited for reliable testing of wires and cables. Moreover, no manufacturer would guarantee a generator to produce an approximate sine wave under these severe conditions of test. The services of Prof. C. A. Adams of Harvard University were secured, and under his specifications such a generator was built and installed, rated at 85 kv-a. All oscillograph records, taken up to the present time and under various conditions of test, have failed to show any departure from a sine wave.

The 50-kv-a. transformer has been replaced by one rated at 75 kv-a., 75,000 volts, operating at a much lower core-density than the former, and taking a much less distorted exciting current. Hence the distorting influence of this current on the generator wave is much less than it was in the case of the 50-kv-a. transformer.

METHOD OF MEASURING VOLTAGE

It is essential to obtain reliable knowledge of the maximum voltage to which the cable may be stressed under the preceding conditions of distorted wave form, if the tests are to be of any great value. Where the wave varies from a peaked to a flat-topped wave, the effective value is only a poor indication of what the maximum voltage may be. The circuit conditions are a function of so many variables that only a wide experience with his apparatus enables an operator to know what wave form may be expected under any given set of conditions.

The spark gap immediately suggests itself, as a means of determining these peak values. Although the needle gap is not conceded to be a device of high accuracy, it is accurate enough for the work in hand. There are objections to its use, however. The voltage can only be determined by connecting the gap in parallel with the cable to be tested, and noting the transformer primary voltage when the gap breaks down at the predetermined value at which it is set. This is a very dangerous practise, as a disturbance is created in the highly oscillatory circuit already described, and cables have often been known to puncture at a voltage apparently much less than their rating, and after the gap had actually broken down. The spark gap can therefore be used only with considerable care, and the danger of a surge is always present. Furthermore, it is not a piece of apparatus that is easily or quickly manipulated, and is wholly unsuited for a testing room where a large number of tests must be completed in a short time.

The oscillograph in its ordinary form is a very satisfactory

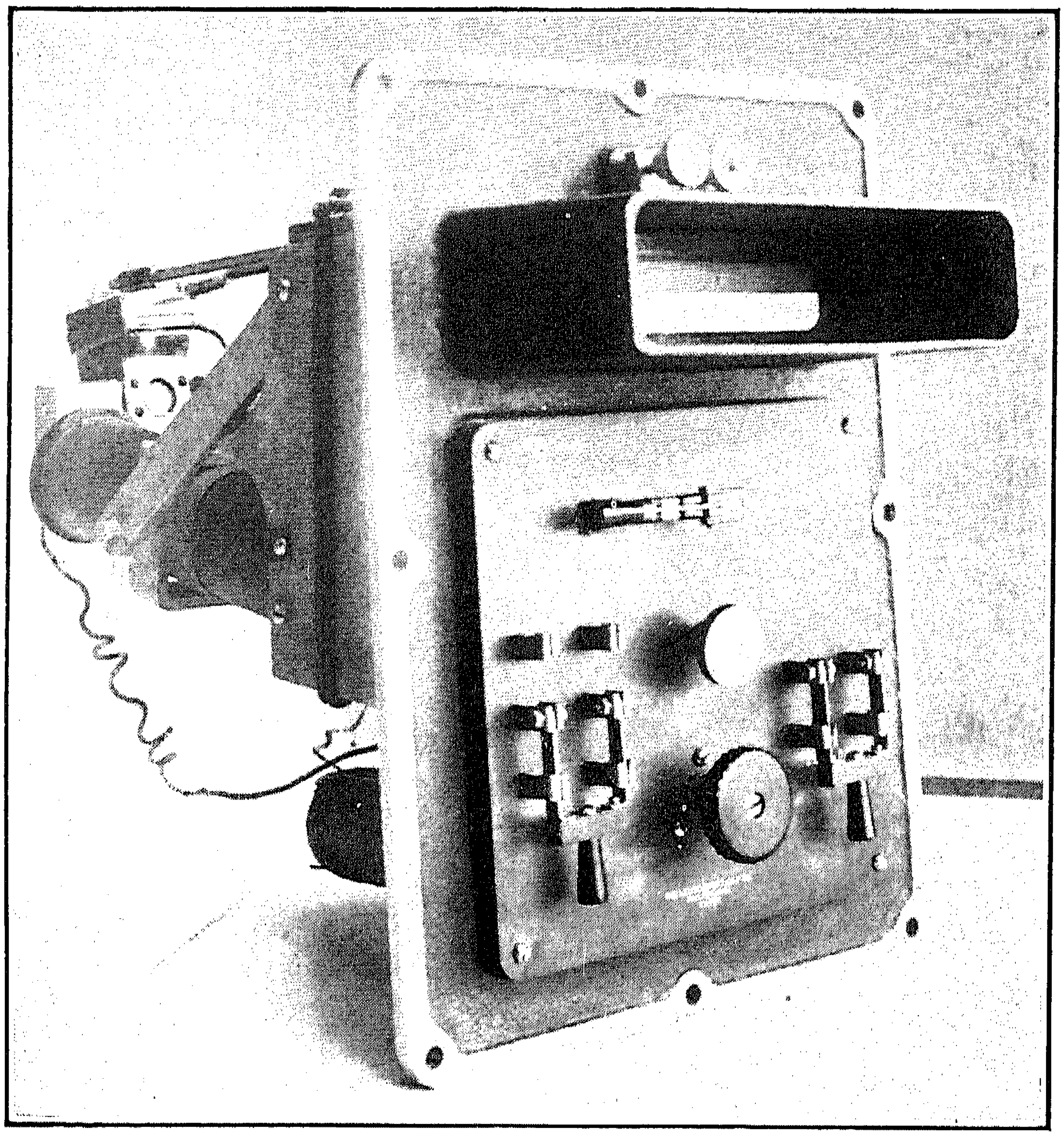

FIG. 20 [MIDDLETON AND DAWES]

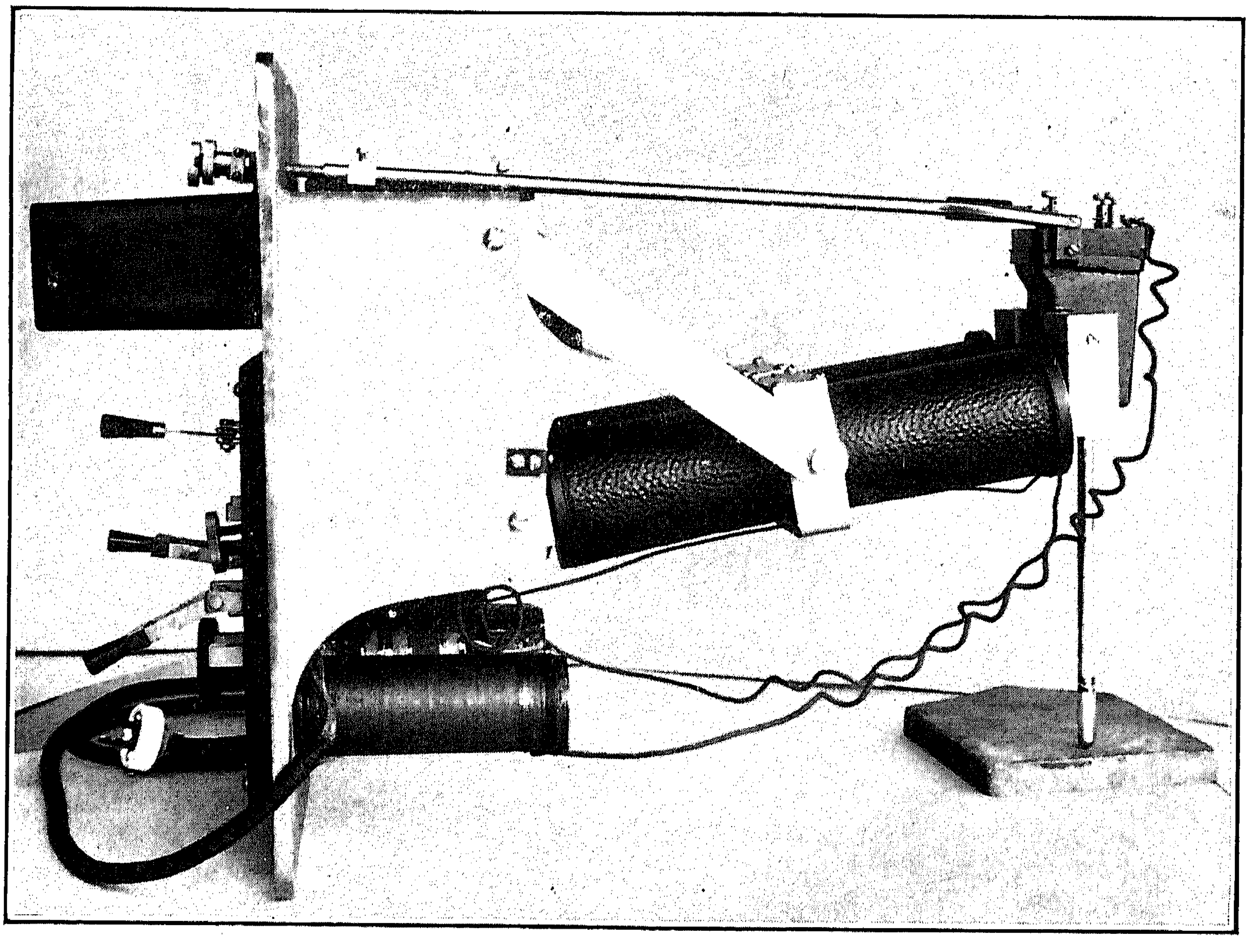

FIG. 21 [MIDDLETON AND DAWES]

piece of apparatus for experimental work, but it requires considerable attention, is clumsy to handle, requires skill to manipulate, and it does not hold its calibration for any considerable time.

Prof. F. A. Laws of the Massachusetts Institute of Technology, and the writers, have, however, adapted the oscillograph principle to an instrument which may be placed directly on the switchboard, and from which the peak value of any voltage wave may be quickly and accurately determined. A sectional view of this instrument is shown in Fig. 19, and is almost self-explanatory.

The lamp, having a straight tungsten filament, is mounted so that its distance from the vibrator may be adjusted to suit the optical requirements of the system. The light then passes through suitable spherical lenses to the vibrator, from which it is reflected through a cylindrical lens to the ground glass screen, where the peak of the voltage wave may be determined from the extremity of the band of light.

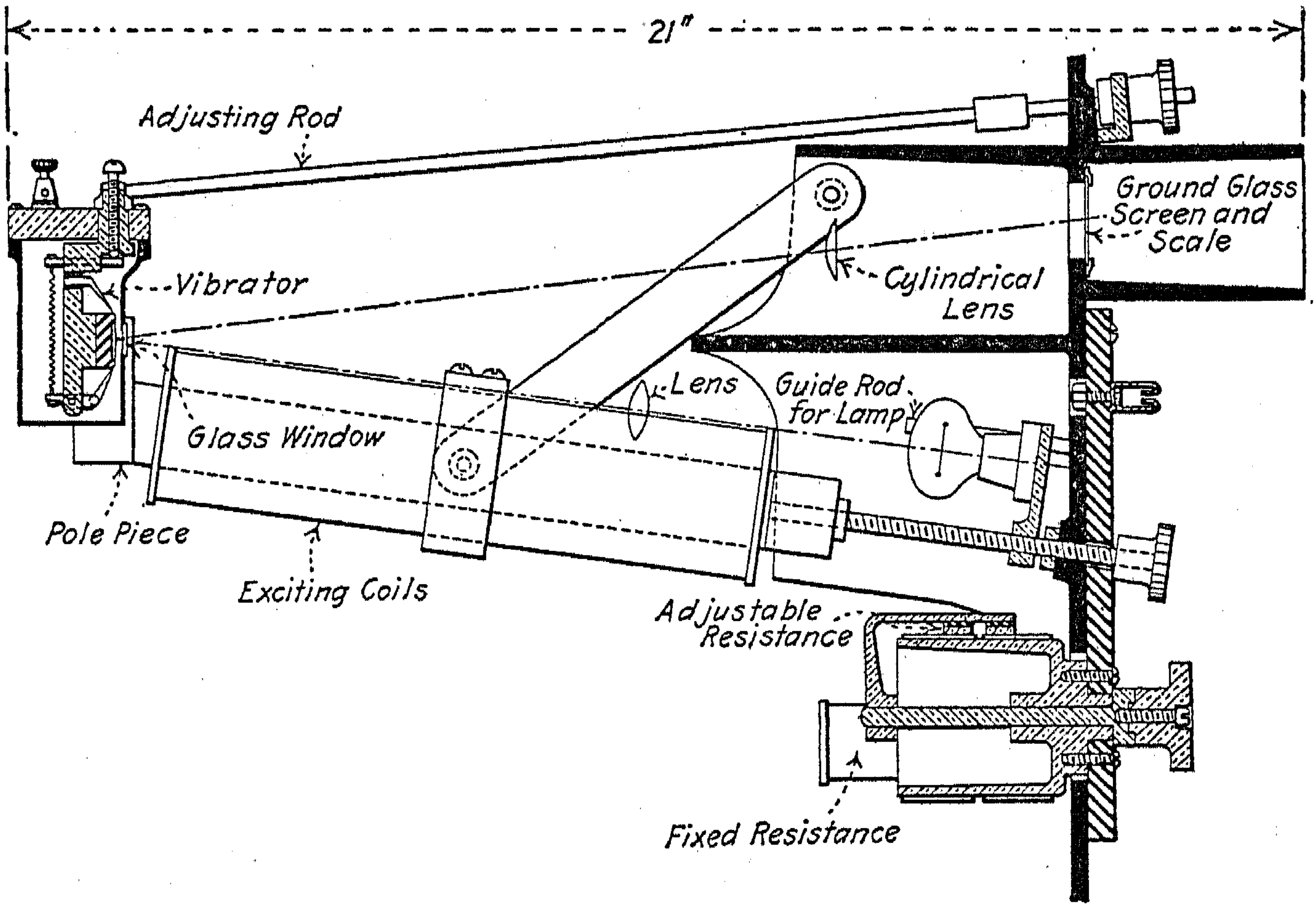

FIG. 19—SECTIONAL VIEW OF SIMPLEX VIBRATING VOLTMETER

The necessary vertical and horizontal adjustment of the beam of light can be made from the front of the switchboard by means of two milled heads which actuate the two adjusting rods. To compensate for changes in the amplitude of vibration due to variations of temperature and other causes, an adjustable rheostat is connected in series with the vibrator, and by throwing the vibrator circuit on direct current, with a double-throw switch, the calibration can be quickly and accurately made. A double scale is also provided. The magnets are operated at high saturation, so that fluctuations in exciting current affect the instrument but slightly. The instrument as used, is connected to the secondary of a potential transformer, whose primary is connected directly to the high-tension circuit. Other views of the instrument are shown in Figs. 20 and 21.

To the manufacturer the importance of this type of instrument is evident. He is aware of the maximum stress at which his cables are being tested at all times, regardless of generator and transformer wave-form. No additional factor of safety is necessary in the cable due to uncertainty on this point. Furthermore, purchasers and inspectors can be quickly and convincingly shown that their cables are being tested at the specified voltage, without employing a troublesome oscillograph or a spark-gap, and without exposing the cable to the dangers accompanying the use of this latter device.

This instrument is not only useful for cable-testing, but can be employed to advantage where apparatus other than cables must undergo potential tests. The e.m.f. waves of all testing-generators are not sinusoidal, even at light loads, and their wave-form may change with the field excitation.

When the e.m.f. is taken directly from a commercial circuit supplying other loads, this voltage wave may vary with the load and the number of generators on the system, as well as through the compensators and other control devices employed.

This voltmeter is also capable of indicating slow-period transients which the ordinary type of meter, owing to its inertia, cannot follow. Instances of this have come to the writers' attention in the cases already cited, when the voltage was being raised on a cable. In a certain power system, it was found necessary to change the lightning arresters from 2300 to 3300 volts owing to the fact that continual discharges were taking place due to a considerable length of submarine cable having been added to the system. Whether this was due to a change in wave-form or to surges, the writers are not prepared to say, but such an instrument would have quickly given the required information.

In closing the writers wish to express their thanks to Prof. F. A. Laws, of the Massachusetts Institute of Technology, for his part in the development of this instrument; to Mr. W. G. Wolfe, of Boston, for his assistance in developing the optical system; to Professors C. A. Adams, H. E. Clifford, and A. E. Kennelly of Harvard University, for their helpful suggestions and criticisms during the preparation of this paper.

DISCUSSION ON "VOLTAGE TESTING OF CABLES". (MIDDLETON AND DAWES), DETROIT, MICH., JUNE 25, 1914.

W. A. Del Mar: The factor of safety of an insulated wire or cable, being the ratio of the breakdown voltage to the normal operating voltage, cannot be determined experimentally without testing the insulation to destruction. It can, therefore, never be definitely known in practise, although susceptible of approximate predetermination in the absence of faults, by calculation based upon tests. If, however, we define the *factor of assurance** of an insulated wire or cable as the ratio of the test voltage to the normal operating voltage, we can provide an experimental basis for the comparison of voltage tests. Thus, if a cable for operation at 11,000 volts is tested at 25,000 volts, we have a factor of assurance of 2.27. If the breakdown voltage is 75,000 volts, the factor of safety is 6.82, and the ratio between the safety factor and the factor of assurance is 3.0.

Two principles are now contending for recognition in the standardization of voltage tests. One is that insulated wires and cables should be tested to give a fixed factor of assurance, and the other that they should be tested to as high a voltage as they will stand without injury to any part of the insulation which may be free from defects. The latter principle is equivalent to a fixed and small ratio between the factor of safety and the factor of assurance.

Mr. Middleton recommends the latter principle, and I believe that he is right for the following reason: If a defect exists in the insulation of a wire or cable it may not be revealed by a test voltage two or three times the working voltage, but may cause a breakdown in service after the cable has been subjected to the strains of installation and operation. Hence a test which provides an apparently ample factor of assurance may not be sufficiently severe to assure the greatest reliability of operation. If, on the other hand, the breakdown voltage is calculated from the known dielectric strength of the insulation, a test voltage can also be calculated which will eliminate defects without injuring those parts of the insulation which are free from defects.

At high voltages, these two principles lead to the same results, as the thickness of insulation is usually proportioned to give a reasonable factor of assurance.

Working on the principle outlined above, the Wire and Cable Committee of the Association of Railway Electrical Engineers arrived at the following test voltages, which are somewhat lower than those given by Mr. Middleton. These test voltages are given in Tables I and II and Fig. 1, herewith. The difference may be partly due to the fact that most of the manufacturers have testing generators with less perfect characteristics than the one described in the paper under discussion.

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*Proposed by Mr. F. J. White and incorporated in Standardization Rules of A. I. E. E., 1914.

The voltages in Table I were calculated by a formula similar to Mr. Middleton's except that the effective thickness of insulation was assumed to be slightly less than the nominal thickness, due to irregularities in manufacture and installation. An example of the former type of irregularity is the eccentricity of the insulation with respect to the wire, and of the latter, the reduction of insulation thickness on the outside of bends.

TABLE I.

TEST VOLTAGES, KILOVOLTS

FIVE-MINUTE TESTS

30 per cent *Hevea* Rubber Compound—Use 100 per cent of following voltages. Varnished Cloth—Use 75 per cent of following voltages. Impregnated Paper—Use 75 per cent of following voltages.

Size of Conductors.	Thickness of Insulation, 64th Inch.							
	2	3	4	5	6	7	8	10
18 A. W. G.	1.0	2.5	4.5	5.5	6.5	7.5	8.5	10.5
16	1.0	2.5	4.5	5.5	6.5	7.5	8.5	10.5
14		2.5	5.0	6.0	7.0	8.0	9.0	11.0
12		2.5	5.0	6.0	7.5	8.5	9.5	11.5
10		3.0	5.0	6.5	8.0	8.5	10.0	12.0
8		3.0	5.0	7.0	8.0	9.5	11.0	13.0
6			5.0	6.5	8.5	10.0	11.5	14.0
4			4.5	6.5	8.5	10.0	11.5	14.5
2			4.0	6.0	8.0	10.0	12.0	15.0
1			4.0	6.0	8.0	10.0	12.0	15.5
0				5.5	8.0	10.0	12.0	15.5
00				5.0	7.5	9.5	11.5	15.5
000				5.0	7.5	9.5	11.5	15.5
0000				4.5	7.0	9.0	11.5	15.5
250,000 cir. mils				4.0	6.5	9.0	11.0	15.5
500,000				2.5	5.0	7.5	10.0	14.5
750,000						6.5	9.0	14.0
1,000,000						5.5	8.0	13.0
1,250,000							7.5	12.5
1,500,000							7.0	12.0
1,750,000							6.5	11.5
2,000,000							5.0	10.5

(For intermediate sizes use the voltages corresponding to the next larger size, having the same thickness of insulation.)

TABLE II.

TEST VOLTAGES, KILOVOLTS

		Thickness of Insulation, 64ths Inch.								
		12	14	16	18	20	22	24	26	28
6-5 A. w. g.........	Rubber..........	16	18	20	22	23	25	26	28	29
	V. C. or Paper......	15	17	19	21	23	26	28	30	31
4-2 A. w. g.........	Rubber............	17	19	22	24	25	26	28	29	30
	V. C. or Paper......	15	17	20	23	25	28	30	32	34
1-0000 A. w. g......	Rubber............	18	21	23	25	27	28	30	31	32
	V. C. or Paper......	16	19	22	24	27	30	32	34	36
250,000 cir. mils	Rubber............	19	22	24	26	28	30	31	33	34
and larger.........	V. C. or Paper......	17	20	23	25	28	31	33	36	38

While the logarithmic formula is useful in calculating the test voltage for a given size of conductor and thickness of insulation, it is dangerous for calculating the thickness of insulation for a given working voltage, as mechanical considerations generally dictate the use of more insulation at low voltages than is indicated by considerations of dielectric stresses. The requirements of the National Electrical Code for wire insulated for 0 to 600 volts represent the results of experience as to the minimum thickness of insulation which has been found necessary in practise. The thickness should seldom be less than required by the Code and should sometimes be more, regardless of voltage.

It should be noted that the formulas given in this paper do not take into account the difference in dielectric stress due to the size of strands in the cable. This has been treated by Prof. Levi-Civita in a paper by E. Jona in the Transactions of the International Electrical Congress, 1904. It would be interesting to hear whether Mr. Middleton's experiments agree with Prof. Levi-Civita's calculations.

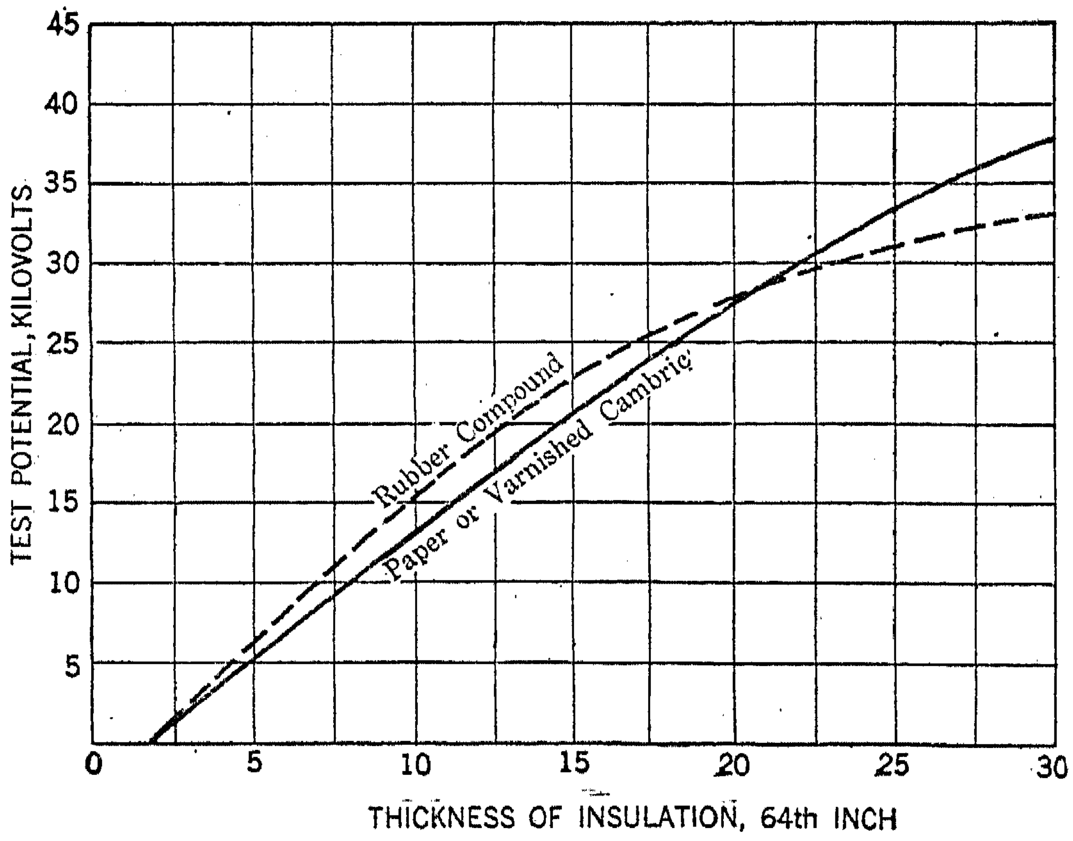

FIG. 1

I regard the paper by Messrs. Middleton and Dawes as one of the most important that has ever appeared on this important subject and believe that it will exert a strong influence in the rational standardization of voltage tests of wires and cables.

C. O. Mailloux: On the second page the authors speak of paper as an insulation for wires and cables. There is a third method of making high-tension cables, which consists in wrapping the conductor with a previously prepared paper. The paper, which is first treated with an insulating compound, is wrapped into rolls; and then the conductor strand from which the cable is to be made is wrapped around with this treated paper to the proper thickness, after which the cable covering is placed on the whole. The cable is then submitted at once to the proper test. The process is shorter and simpler, and less expensive than the other processes of preparing the cables with dry paper, subjecting them to a vacuum, and then treating them with compound. There is an English firm which makes high-tension cables according to that process. I understand they have given satisfactory results, though I am not informed as to the comparative results. It would seem that if the method lends itself to the preparation of insulated cables for high tensions, and if such cables can withstand high tensions, the process would have some advantages: One could make sure more easily that every portion of the insulating material would be properly treated with the compound, and also that all of the defective parts of the insulating paper were eliminated or removed. On the other hand, there is the difficulty resulting from the possibility of entrained moisture at the time of laying the insulating paper around the conductor. It would seem very difficult, in an ordinary atmosphere, to keep out dust and also moisture, so that, as the insulated paper is wrapped around the conductor, one might easily understand that there would be air bubbles, particles of dust, and particles of moisture imprisoned in the cable, whereby the quality and the durability of the insulation would be impaired.

Henry G. Stott: I was about to call attention to the point that Mr. Del Mar brought up in his discussion, which is that it may be open to inference from the statement here that if there is a large diameter, it would be feasible to reduce the thickness of the insulation. I do not think the authors desire to convey that idea, but it may be drawn as an inference from this paper that it could be done. From a purely electrical standpoint it could, but from a mechanical standpoint we must have heavier insulation with a large conductor than with a small conductor. That should be emphasized, as some might take advantage of the curve to say that they could reduce the insulation on 500,000-cir. mil cable, but if they did so, they would get into trouble later on.

On page 1193, at the bottom of the page, is a paragraph on over-stressing cables. That is a point we have heard a great deal about in the last fifteen or twenty years. We have had in use now several hundred miles of cable over 15 years. These are all high-tension cables, and they are put under tests at 2.5 times working potential once a year. There is not the slightest sign of deterioration in the cable, after fifteen years' use. In fact, some of these cables were originally designed for use on 6600 volts, and are now being used on 11,000 volts, and in spite of this we have had this 2.5 times pressure test on them once every year, and many of them have had it as many as eight or ten times a year, due to cable changes, etc. Each time the cable is cut for any purpose, it receives the breakdown test, and once a year on general principles it receives a breakdown test.

We should prefer to have the cable break down on test, rather than in practical operation. While theoretically there may be some result of over-stressing of cables, yet practically, based on fifteen years' experience, with many hundreds of miles of cables, we have not yet found that to be so.

E. E. F. Creighton: I should like to ask Mr. Middleton something of the theories—he said there were many—to explain why a short piece of cable will stand so much more potential than a longer piece.

Charles L. Fortescue: I want to call attention to the very common mistake in attributing the third harmonic distortion of the transformer to the hysteresis. The distortion in the transformer is directly due to the cyclic variation in permeance, a small part of which is caused by hysteresis. Hysteresis produces no distortion.

In connection with the proposed method of measuring maximum voltage of high potential, Mr. Chubb and I at last year's mid-winter convention described a method of measuring the maximum value of the wave on the high-tension side, using a condenser. The average value of the charging current of the condenser across which high voltage is impressed is directly proportional to the product of the maximum voltage and the frequency of the impressed wave. This is a very simple way of measuring the maximum value, and it is quite reliable. I do not think a method of measuring the maximum value of the wave which requires a voltage transformer is reliable. The fact that a sine wave generator is used does not prevent third-harmonic distortion in the step-down transformer itself, which, due to its distributed capacity and inductance, may be quite large.

The third-harmonic distortion due to the step-up transformer will also be enhanced when transformed by the step-down transformer, so that as a means of measuring the maximum of the secondary voltage of the step-up transformer the proposed method will not lead to correct values. It is better to measure the maximum value directly by the method we have described or else by some modification, such as that described by Dr. Whitehead in his paper presented yesterday (*The Electric Strength of Air—V*).

Some question has been raised as to why long cables break down on test more easily than short cables. I think this is due to the combined effect of the distributed capacity and self-induction of the cable. When the voltage is supplied to the end of the cable, which is usually coiled on a spool, the actual average voltage in the cable, in the case of a long cable, is much higher than the voltage at the end, due to the effect of distributed capacity and inductance. It may, in long cables, be 15 or 20 per cent higher at the end of the cable than at the point where the voltage is applied. I think this may possibly be the reason why a long cable breaks down more easily than a short cable.

Percy H. Thomas: I will ask Mr. Middleton a question. He has discussed the effect of the third and other harmonics on the maximum voltage which may be impressed on a cable. It occurs to me that there is another effect of the high frequency which may possibly be important, and that is its heating effect. The insulation of an underground cable is stressed severely. The alternating electric stress causes a certain amount of heating within the material. That heating at 60 cycles, we will say, is almost negligible. At 180 cycles, or 200 or 300 cycles, that heating may be very important. A third harmonic, or fifth harmonic, so located with regard to the fundamental as to reduce the voltage peak, might develop heat enough within the dielectric, especially at any peak point, to raise the temperature to the puncturing point. I would like to know if anything has been done along that line of investigation.

The other question is about the puzzling fact that a long cable apparently breaks down at a lower voltage than a short cable. I would like to see two tests made, one with an outfit such as described by Mr. Middleton, comparing a long length with a short length cable, and a second test comparing a long length with a short length of cable, made according to Mr. Stott's generator method. Tested by the former method, you might find a marked difference between the voltage of failure in the short and long length of cable. Tested by the large generator, on the other hand, you might find there was not so much difference. This matter of the distortion of the wave by the large charging current of the long cable with the possible introduction or magnification of the high-frequency harmonics, may mean that there is produced a high-frequency effect in the test of the long cable, which does not exist with the short cable.

J. R. Craighead: In respect to obtaining a voltage supply, a generator which gives a sine wave is the most satisfactory, provided it will maintain the sine wave under testing conditions, but as the author states, those generators are rather rare, especially when loaded on a capacity load of pretty near their limit.

There is an alternative way which consists in using any ordinary line potential of a normal commercial wave form, and with a sufficient power, so that the capacity effect on the line wave is absolutely negligible. If this is taken through a transforming outfit of considerable reactance, it is not difficult to obtain a wave which more closely approaches a sine than the line wave itself. This was tried out to some extent in the high-potential testing of large turbine generators, obtaining by the oscillograph the wave forms on the high- and low-tension sides of the step-up transformer, and also the line wave, back of the regulating apparatus. For most large capacities it is not very difficult to get the correct amount of reactance so that the wave form across the machine under test is satisfactory.

In regard to the voltmeter described, the use of the oscillograph for this purpose was described and the suggestion of an elementary oscillograph-voltmeter was made in a paper by Mr. L. T. Robinson and Mr. J. D. Ball presented two years ago at the Boston convention, entitled *Permeability Measurements with Alternating Current.* (TRANS. A.I.E.E., 1912, Vol. XXXI, p. 1609).

W. I. Middleton: The point brought up by Mr. Stott and Mr. Del Mar is very well taken. We should possibly have mentioned the fact that we could not depart from the Underwriters' specification. We realize that the heavy conductor does require a thicker wall of insulation for mechanical purposes, and that we did not mention this specifically, was an oversight on our part.

In regard to the long and short lengths of cable, and the difference in their ability to withstand voltage strain and test, I too am looking for information. We had an interesting paper in New York last winter on the testing of cambric insulation with different size electrodes, and I must say that Mr. Farmer's experience with electrodes bears out my experience with the long and short lengths of cable. Further, some time ago there was a paper written, I think by Mr. Moody, on some corona tests, and it was then found that, with a short length of bare wire, corona started at a much higher voltage than it did with a long length. So apparently the same phenomenon occurs here as in other insulating materials, which, to my belief, breaks down the law of probability.

Mr. Thomas spoke about the long and short lengths of cable and also mentioned the effect of heating. We have tried to be very careful about this matter of heating, and so have recommended short period testing. Many tests require only one minute. We usually ask for five-minute tests, as we believe that this eliminates the question of heat. Then, again, these cables are generally submerged in water when they are under test, and the question of heating, under those circumstances, I believe, is almost entirely eliminated.

When a long time test is attempted a multitude of different factors are encountered, and the effect of ozone generated at the ends of the cable, which attacks the rubber insulation, gives rise to a lot of theories regarding the piling up of voltage on the ends of the cable, etc. We have tried to eliminate these factors in our regular practise, realizing that we are obliged to make many tests in the course of the day, and all of this work is carried out on commercial lengths of cable, as they pass through the test room of the factory.

Chester L. Dawes: In regard to Mr. Stott's remark as to the application of this formula to the calculation of the wall of the insulation, mechanical as well as electrical considerations must necessarily be taken into account. When the cable is once designed, the wall being of the proper thickness to take care of the mechanical and electrical stresses to which it will be subjected in service, the test voltage should be determined by this formula or one that is its equivalent, in order to be certain of breaking down any defects which may exist in the insulation.

As to Mr. Fortescue's remarks, I agree with him that the third harmonic is also due to changing permeability, but hysteresis necessarily represents changing permeability. If the iron could operate without hysteresis, the third harmonic might yet be present, of course.

The method which he suggests for measuring the peak voltage I admit is correct, but it must be remembered that a device to be used in the test room should be direct-reading and capable of being used and used rapidly by a testing room employee.

Referring to the distortion of the voltage wave through the potential transformer, we took one oscillogram on the primary of the step-up transformer, and another one on the secondary of the potential transformer, thus stepping-up and stepping-down, and we could discern no difference in the oscillograms.

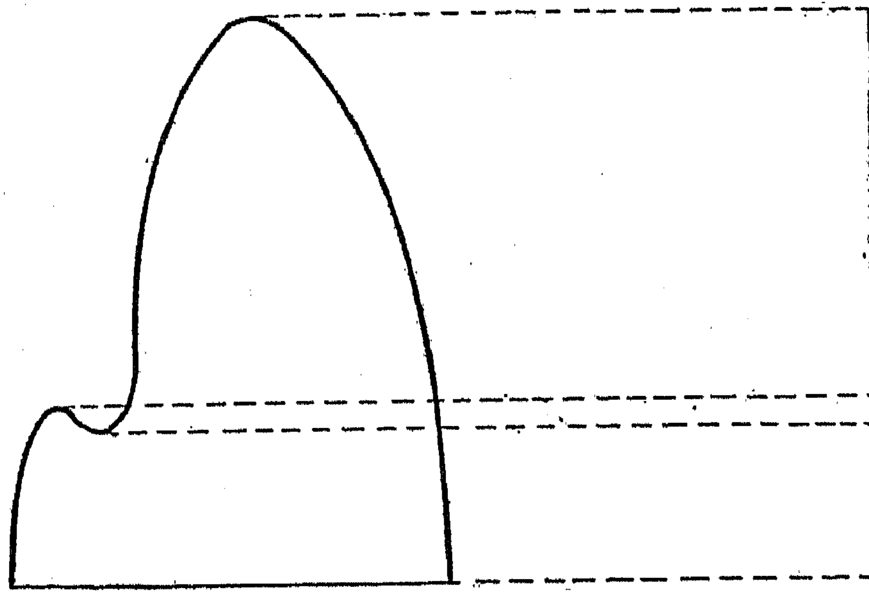

FIG. 2

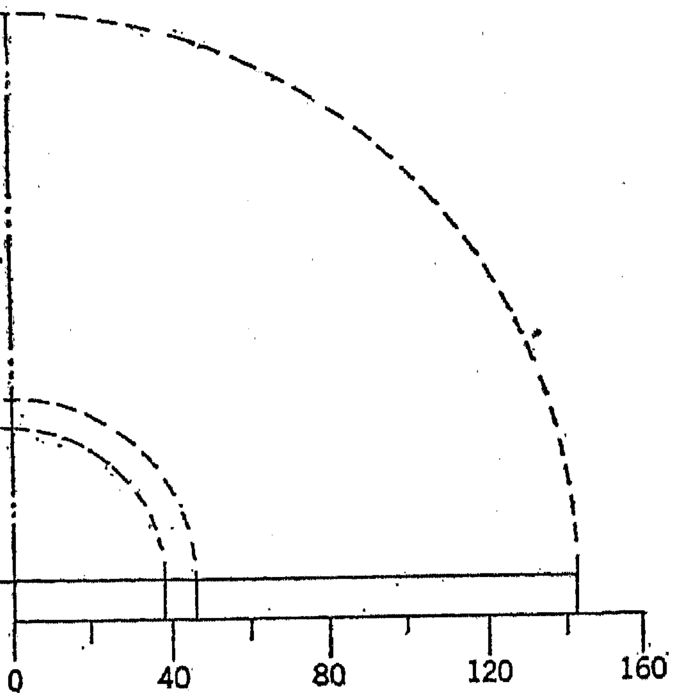

FIG. 3

We had a very distorted wave under these conditions. Frequently we have looked into the oscillograph, without taking records, and have never been able to discover any difference between the wave form on the primary and that taken from the potential transformer secondary.

To have the voltage pile up in a long length of cable, inductance must be present. When the cable is installed, the inductance is very small, and, therefore, the probability of the voltage piling up is very slight.

In regard to Mr. Craighead's suggestion as to obtaining a sine wave with reactance, I assume that he means connecting the reactance in series with the transformer primary. This method could not be used in the test room, because it is too unstable a combination; and the operator would not readily understand how to adjust for a sine wave under each set of conditions. Further, resonance difficulties would be experienced, that is, the circuit might become sharply tuned, and a high voltage might suddenly pile up on the cable. As I have just stated, it is necessary to have a method of measuring the peak voltage which the ordinary switchboard operator can understand and easily manipulate.

As to the voltmeter, I may add that a general idea of the wave form is obtained by observing the band of light. For instance, with a wave of the type shown in Fig. 2 (many of this type are shown in the oscillograms) the light on the scale will have the general appearance shown in Fig. 3. The light at the points corresponding to the lower peak and to the depression will be more intense than it is at other parts of the scale. In the same way, a flat-topped wave shows a much more intense light at the end of the scale than a peaked wave does. Similarly the tooth ripples are readily discerned.

Presented at the 31st Annual Convention of the American Institute of Electrical Engineers, Detroit, Mich., June 26, 1914, under the auspices of the Electrochemical Committee.

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STERILIZATION OF WATER BY ULTRA-VIOLET RAYS OF THE MERCURY-VAPOR QUARTZ LAMP

BY M. von RECKLINGHAUSEN

Abstract of Paper

Mercury-vapor quartz lamps are applied industrially for the production of ultra-violet rays for the sterilization of water.

To obtain ultra-violet rays economically it is important to study the temperature of the luminous part of the lamp.

There are different ways for measuring the ultra-violet power, based on physical, chemical or bacteriological reactions. Such reactions are compared between them.

The paper refers to the historical development of mercury lamp water sterilizers and the development of pistol lamps for large sterilizing units.

Different germs are of different sensitivity to ultra-violet light.

It is important that the water should be clear when entering the sterilizer.

Description is given of two typical installations, one in Europe, one in America.

Data are given on the power consumption for the sterilization of water by ultra-violet rays.

WITHIN the last five years a new field for the application of electricity has been created in Europe based upon the electrical production of ultra-violet light for the sterilization of water and for other purposes. As this new industry is now being introduced into this country, it is of interest at this time to analyze its basis and principles.

The experimental and development work in this field has been done mainly in France, and prominently identified with it are the names of Courmont, Nogier, Henri, Helbronner, von Recklinghausen, Vallet and others. This paper deals particularly with the work done by the writer in collaboration with Messrs. Henri and Helbronner at the Physiological Laboratory of the Sorbonne University.

The Source of Ultra-Violet Light

The only industrially-applied source of ultra-violet light is the mercury-vapor quartz lamp. The spectrum is known by its bright lines in the visible part and by a large number of typical lines in the ultra-violet part, as shown in Fig. 1, which is drawn to proportional scale.

When starting this work we soon found that we had to go pretty fully into the question of the measure of the ultra-violet power of the different light sources at our disposal, so as to give the mercury quartz lamps the electrical characteristics which made them most useful for the creation of ultra-violet light. It is a well-known fact that the skin takes a less ghastly hue under the quartz mercury lamp than under the ordinary mercury-vapor lamp. Spectroscopic examination shows that this is due to a considerable increase of the intensity of the red lines in the spectrum of the quartz lamp. This phenomenon was examined somewhat more closely, with the following results:

An ordinary 110-volt lamp was taken, which normally operates at 3.5 amperes and 80 volts; it was operated at different wattages, obtaining thereby, naturally, different temperatures of the mercury arc. A spectro-photometric analysis was made of the five principal colors, composing the visible light of these lamps.

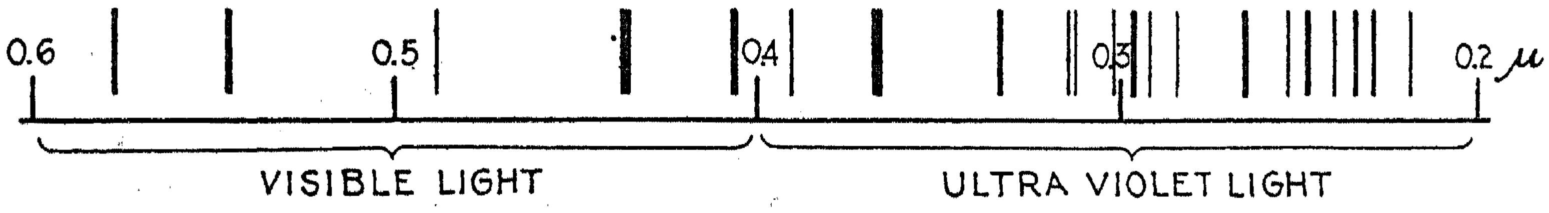

FIG. 1

Assuming the intensity of each color at the lowest wattage as unity, we note that increasing the wattage of the lamp tends to increase the red more than the other colors, as is shown in the curve, Fig. 2. It might therefore be expected that the increase of the ultra-violet rays with increasing temperature of the lamp, would be somewhat like the increase at the violet end of the spectrum, that is to say, proportionately less than at the red end. As will be seen from what follows, this is not the case. There is obtained, on the contrary, a considerably greater increase in ultra-violet than in violet rays with increasing temperature of the lamp.

QUANTITATIVE MEASUREMENT OF ULTRA-VIOLET LIGHT

The candle power standard for ordinary light is not a physical standard but a physiological one, being the effect on the eye of the sum of the visible wave lengths emitted by a defined source of light, produced by a defined fuel, burning in a defined way.

The eye not being sensible to ultra-violet, we only consider the total *visible* energy sent out by this standard lamp. From the start it is therefore clear that if we want to define a standard of ultra-violet light we must do one of two things, namely: either define the standard in energy units (and wave lengths) or imitate our method of defining that standard of ordinary light and define our standard ultra-violet as the unit of effect produced by the ultra-violet rays. However, it is likely that the sums of such effects may be identical if *one kind of an effect is chosen* and may not be identical if another type of an effect is chosen.

The only true way of defining the power of the rays is by the analysis of the spectrum, and the determination of the energy sent out by each wave length. This method, however, is extremely inconvenient and, after all, does not give us what we want in practise.

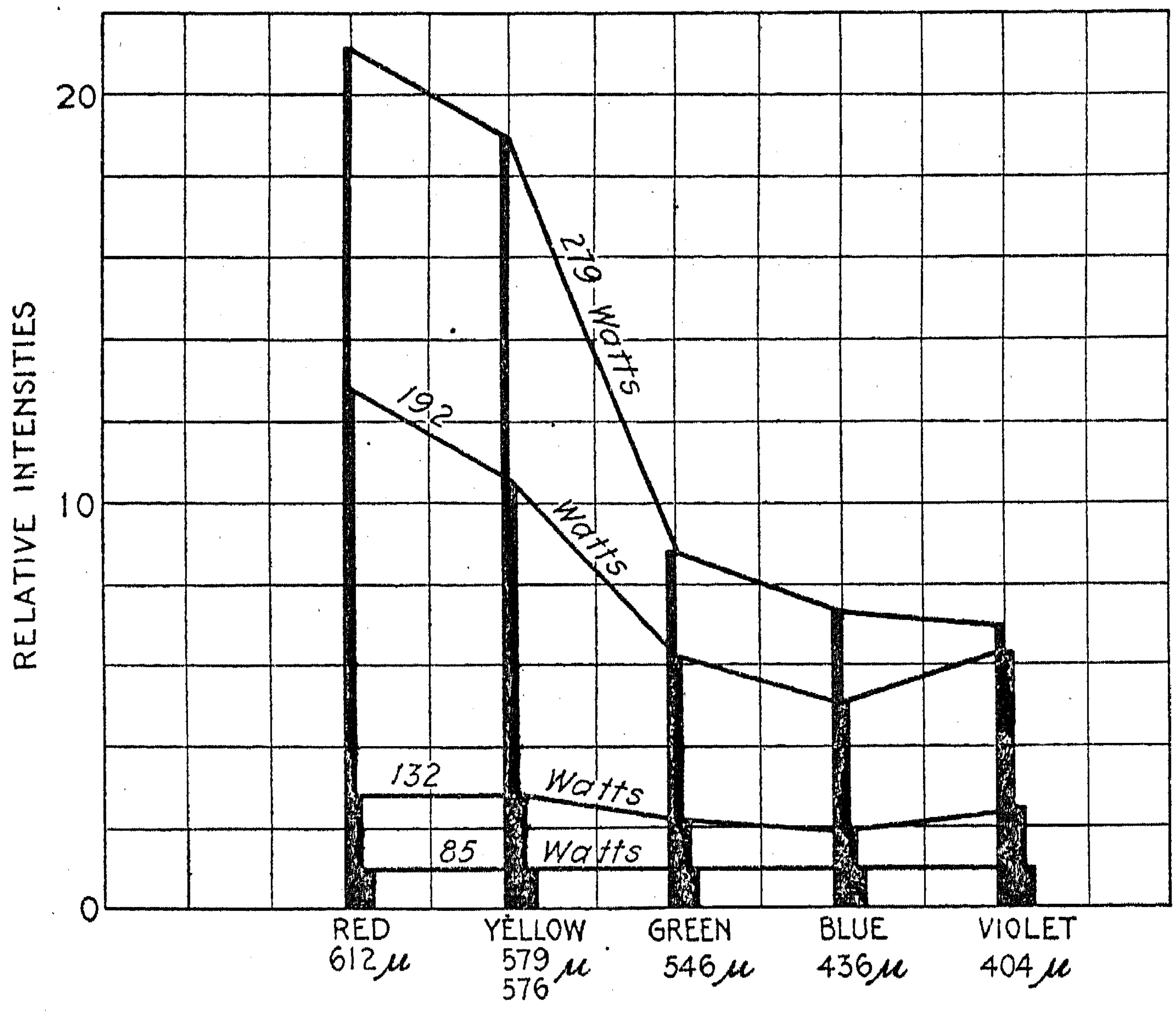

Fig. 2

It is therefore better to choose as a unit, some value of the particular effect which concerns the work in hand. If we want to follow chemical reaction under the ultra-violet light we choose arbitrarily as a unit one in which the desired reaction takes place in a defined way after a unit period of exposure to all the rays of the lamp. We may therefore say that for every type of reaction under the ultra-violet light we have to define a new unit of actinic power.

The different ways of examining the power of the ultra-violet spectrum are the following:

(1) Analysis of the distribution of energy in the spectrum. The way to measure this is to measure the amount of heat developed by a certain wave length, the measurements being made by means of a bolometer or thermoelectric couple.

Fig. 3 shows the distribution of energy in the spectrum of the mercury lamp as worked out by Ladenburg. Fabry has used different filters or screens to separate out different wave lengths. He finds that a 110-volt lamp burning at 27 volts, 3.5 amperes, sends out energy of which the distribution is as follows: 93.7 per cent in the infra-red; 3.6 per cent in the visible spectrum; 2.2 per cent in the ultra-violet spectrum from 0.366μ to 0.313μ; 0.5 per cent in the ultra-violet from 0.313μ down to 0.253μ. As to absolute values, Fabry found that at one meter distance from the lamp, one square centimeter received 125 ergs per second of visible light and 76 ergs per second of ultra-violet light down to 0.253μ.

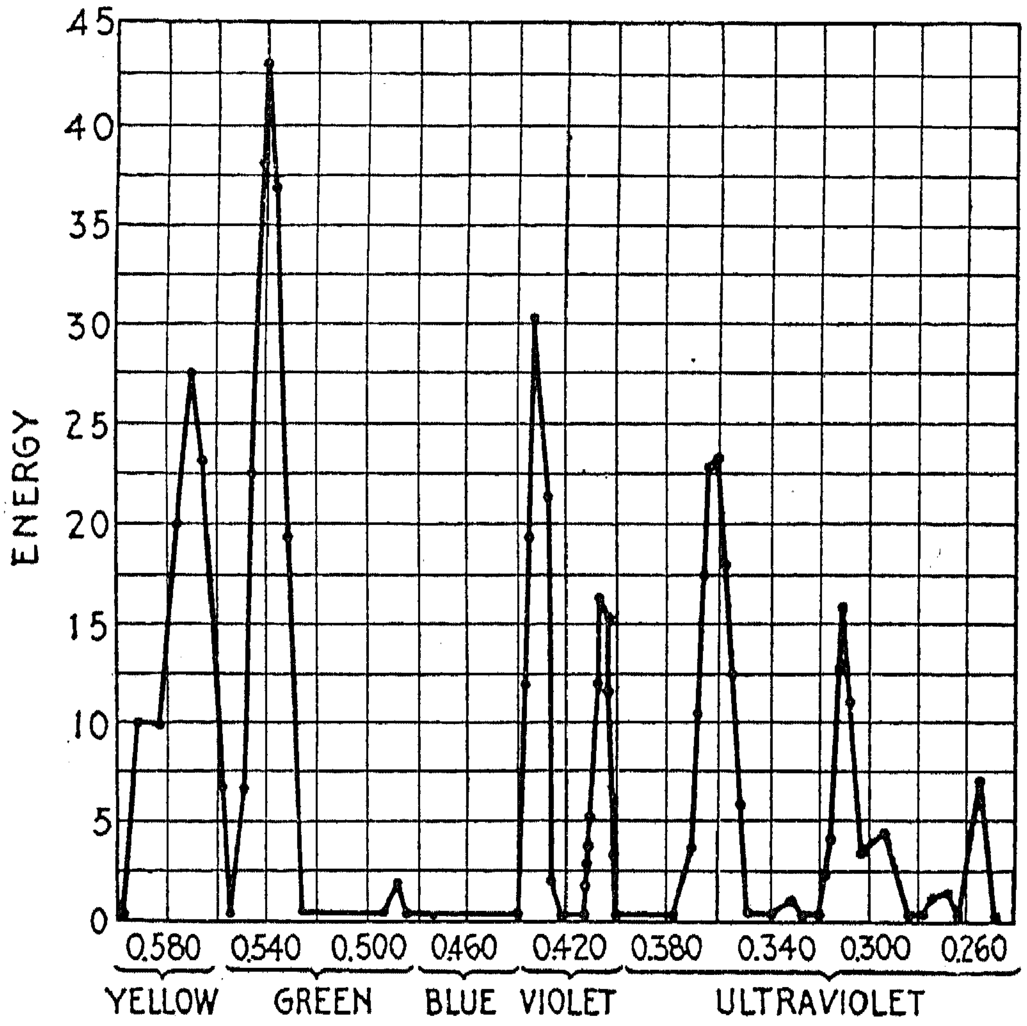

FIG. 3

(2) Ultra-violet light falling on a condenser will ionize the air and this will be followed by a discharge of the condenser. This method could probably be used for analyzing the power of different wave lengths or for establishing an arbitrary standard of ionization by ultra-violet light.

(3) Many chemical reactions are produced to a greater extent by ultra-violet light than by visible light. The so-called Eder reaction of precipitation of calomel, which goes on very much faster under ultra-violet light than under visible light, is an example. The dissociation of gaseous hydrochloric acid and particularly the dissociation of silver salts may also be mentioned. The typical reaction of this latter kind is the blackening of photographic paper; this, for certain types of paper, occurs four times as quickly under a naked quartz lamp as it does under the same lamp with glass interposed, showing thereby that the ultra-violet part of the spectrum has a very much stronger effect than the visible part. The photographic plate allows us to compare the strength of individual lines of equal wave lengths but coming from different sources, by comparing the times of exposure necessary to obtain equally strong pictures of such lines.

(4) Bactericidal or abiotic action. The first real spectrum analysis of this kind we owe to Ward, who threw the spectrum of a quartz lamp on an infected agar plate. The parts of the plate which were exposed to the violet end of the spectrum would not show any growth of colonies, while the parts which were exposed to the red end of the spectrum would develop growth.

With the above-cited chemical reactions it is fairly easy to create a unit; for instance, precipitation of a unit quantity of calomel at the unit distance in the unit time. If, however, we choose a unit of bactericidal reaction, we find that cultures of microbes vary so much with age and other conditions that it is impossible to get sufficiently constant results upon which to base a unit reaction. If we wish, therefore, to use abiotic reaction as a unit we must first determine the sensibility of our reactive material, that is, the germ culture on hand, by exposing samples of it to the light of a lamp which is otherwise standardized. This means creating a laboratory-standard lamp which is so operated that it will always produce the same amount of ultra-violet rays.

The abiotic reaction which we chose as most convenient to handle was the measure of the exposure necessary to kill paramecias, these being similar to water bacteria and fairly easy to cultivate and to observe directly under the microscope, as they have a very violent motion when living and, naturally, no motion when dead. The method of procedure is to take a drop of such culture, expose it at a definite distance under the lamp, count the seconds necessary to make them motionless, and compare the figures thus obtained with figures obtained under the standard lamp.

As the photographic paper method is infinitely more simple to handle, it was considered advisable to see whether it would not correspond closely enough with the abiotic reaction to be a useful check upon the abiotic power of the quartz lamp. Fig. 4 shows the observations made simultaneously by the two methods, using a lamp operating at various voltages. Analyzing the results obtained by methods 1, 3, and 4 with lamps operating at different temperatures (see Fig. 4), we may conclude that the relative increase in ultra-violet rays with increase in lamp voltage is considerably stronger than the increase for the green and blue rays.

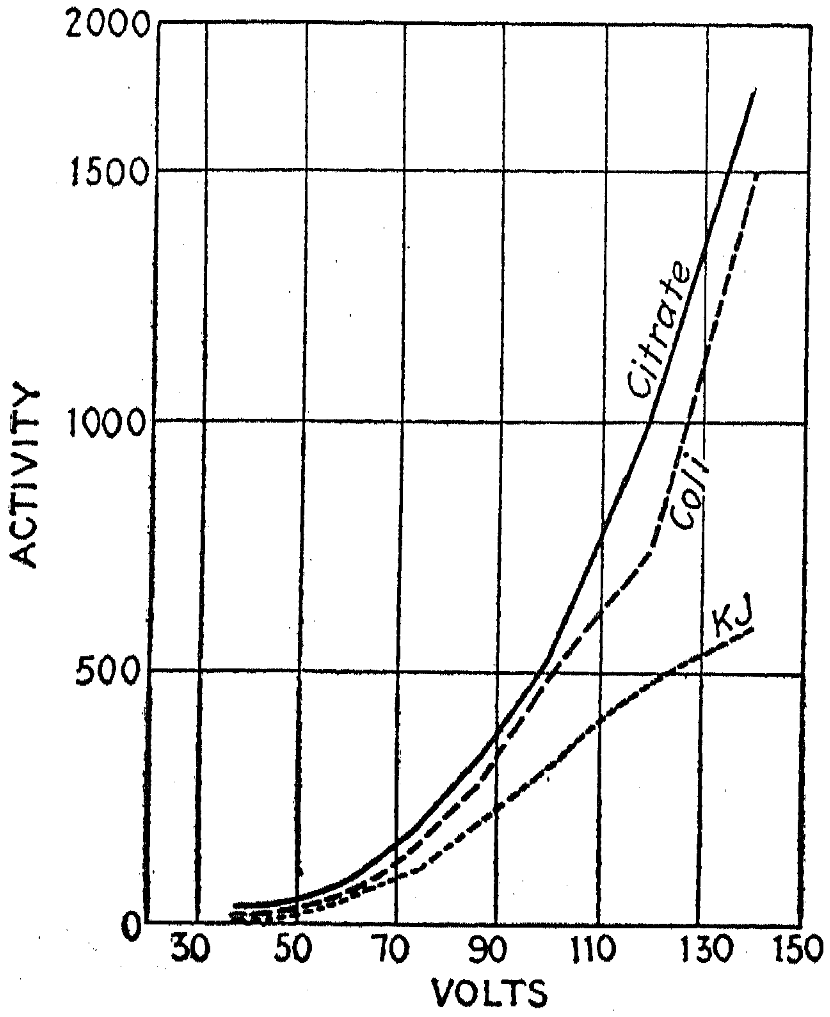

FIG. 4

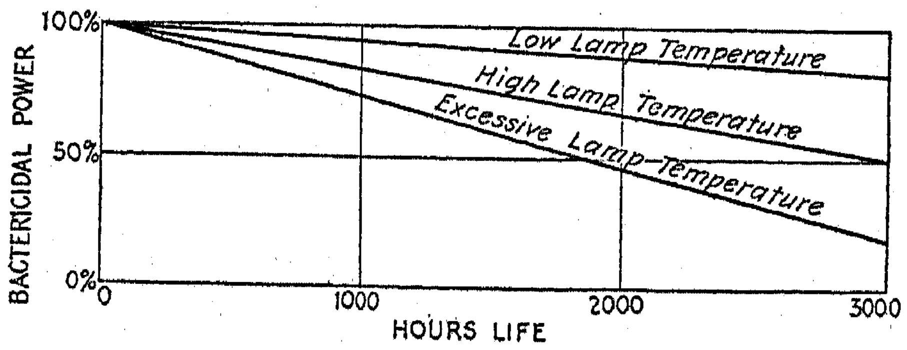

FIG. 5

Having found that we get more ultra-violet rays from a lamp the hotter it is operated, we naturally had to take care not to overdo this and run the lamps at such a temperature that they would suffer thereby in their emission of light, particularly ultra-violet light. It is a well-known fact to everybody who has handled quartz lamps that at a certain temperature they will become almost entirely opaque to light, due to a kind of devitrification of the quartz which gives it the aspect of opaque glass. The maximum temperatures permissible so as to avoid this condition for the illuminating lamps had previously been determined. Some of our experiments for ultra-violet power were made with illuminating lamps which were operated at a somewhat lower wattage than usual. Fig. 5 shows the variation in abiotic action of such lamps, with time. The change, if any, was not very considerable.

On the other hand, Fig. 5 shows that lamps run hotter than illuminating lamps would lose considerably in their abiotic power with time. They evidently approach the limit at which complete opacity of the tube occurs. The problem is evidently exactly the same as for any type of incandescent lamp. We have to determine the working characteristics of the lamps to obtain the optimum of ultra-violet-time efficiency. It is probable that the electric characteristic of lamps for such work has to be chosen so as to obtain a somewhat lower temperature in the luminous part than lamps for illuminating purposes usually have.

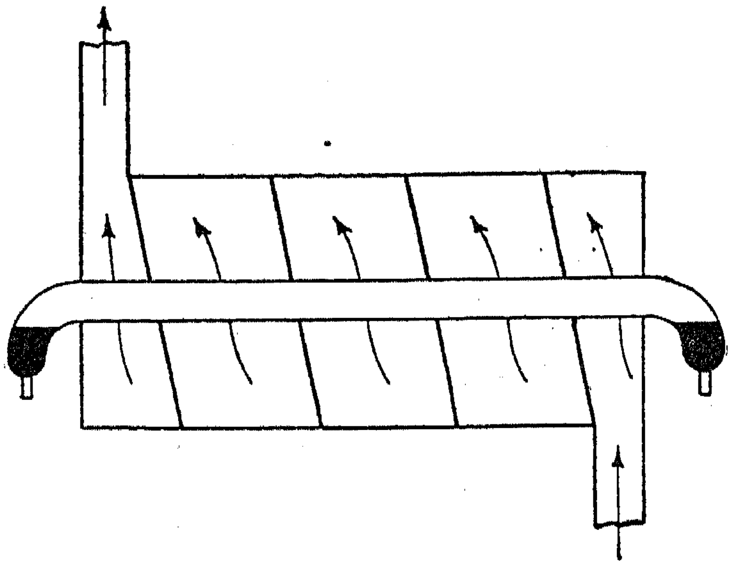

FIG. 6

STERILIZING APPARATUS

The most efficient way for the mercury lamp to react upon water seems to be, *a priori*, to submerge the lamp entirely in the water which is to be sterilized, as proposed in 1906 by De Mare (Fig. 6), and tried in many experiments by Courmont and Nogier (Fig. 7). Direct contact, however, of the water with the heated lamp influences the luminous and ultra-violet efficiency of the quartz lamp to an enormous degree, as may be seen from Fig. 8. It seems to be certain, therefore, that it is better, if one wants to plunge the light source into the water, to protect the lamp from direct contact with the water, and this system has been adopted with modern apparatus. This protection against direct contact can be secured by fusing over the lamp a wide quartz jacket which prevents contact of the light-giving portion of the lamp with the water, as shown in Fig. 9.

Difficulties, however, arose in the manufacture of such jacketed lamps and it was found advisable to construct the apparatus in such a way that the lamp was removable from the protective jacket, as shown with the so-called pistol lamps, Fig. 10, allowing, nevertheless, all the light to enter the water (Fig. 11). Another method is to let the water circulate in such a way around the lamp that it would not come into contact with it, receiving nevertheless practically all the rays emitted by the lamp, as shown in Figs. 12 and 13.

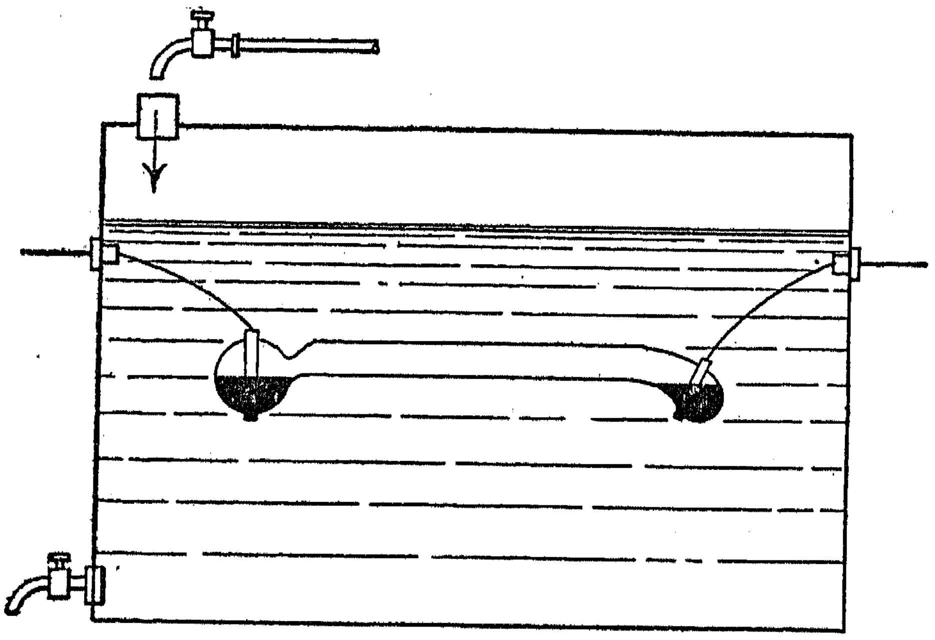

FIG. 7

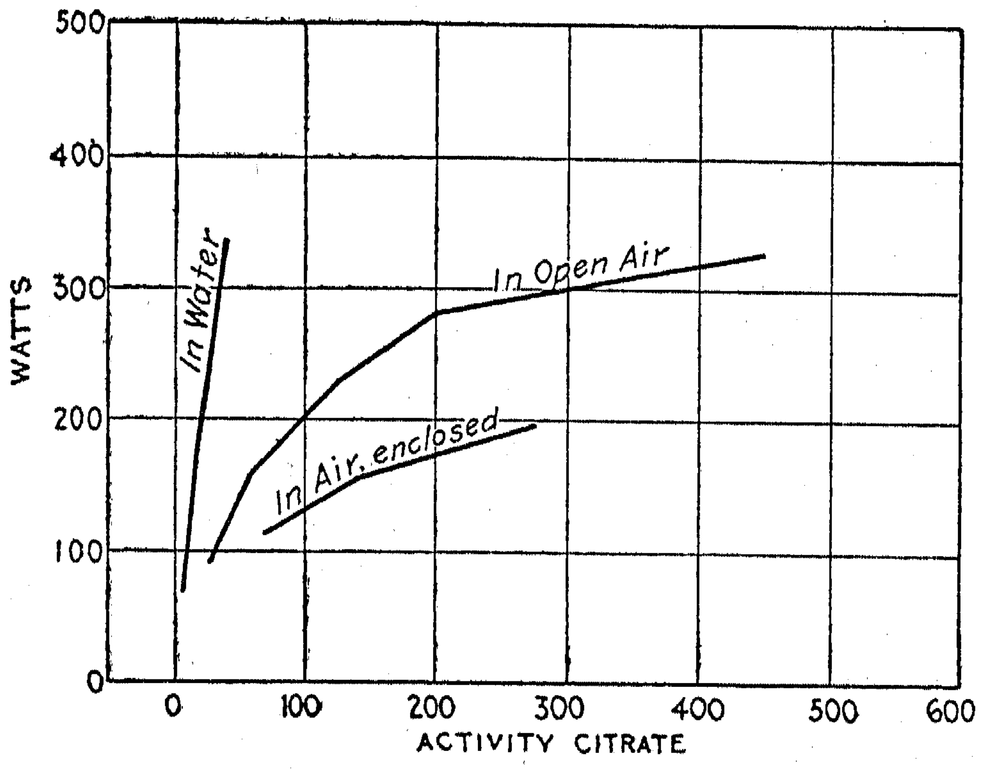

FIG. 8

Where it is more a question of convenience and less a question of efficiency the simplest method is evidently to place the lamp above the water but as close as possible to its surface. (Fig. 14.)

Figs. 15 and 16 show such arrangements which have been used on a large scale. Unfortunately, reflectors placed above such lamps have a low efficiency in reflection of ultra-violet rays. It may therefore be said that with such apparatus hardly half the rays of the lamp will enter into the water.

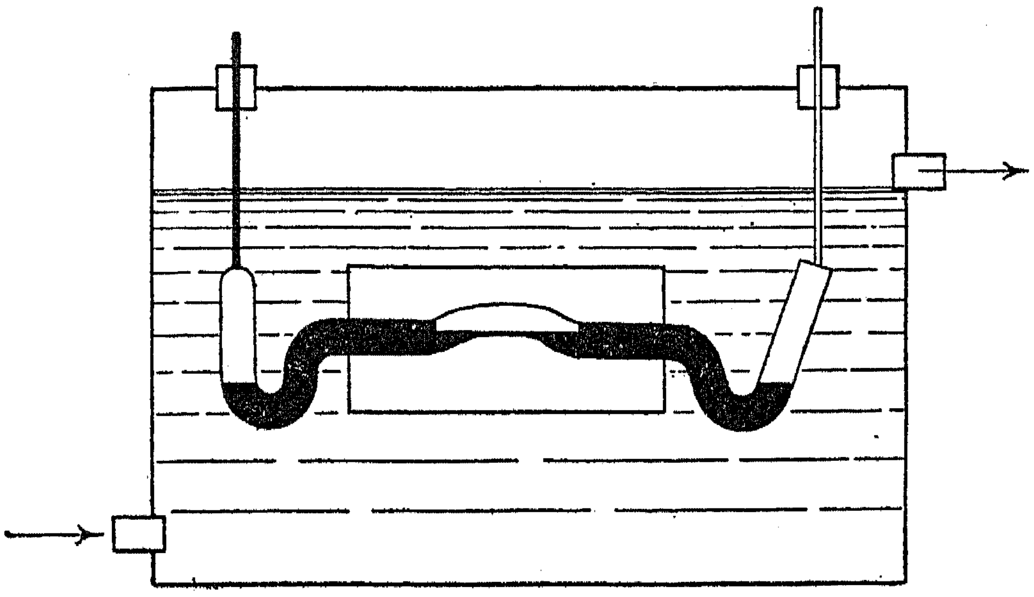

FIG. 9

CONTACT OF THE RAYS WITH THE GERMS

Different germs have different sensibilities to the ultra-violet rays, as may be seen from Fig. 17, which indicates the relative exposures necessary to annihilate different germs under the same illumination. The ones of greatest interest to us are the water bacteria, and we find that they are killed in as short a time as 1/20 second, at a distance one to two centimeters from the powerful ultra-violet ray lamps. Water being practically as transparent as air to the ultra-violet rays, we are therefore certain that if a germ floats in the water it will be annihilated by

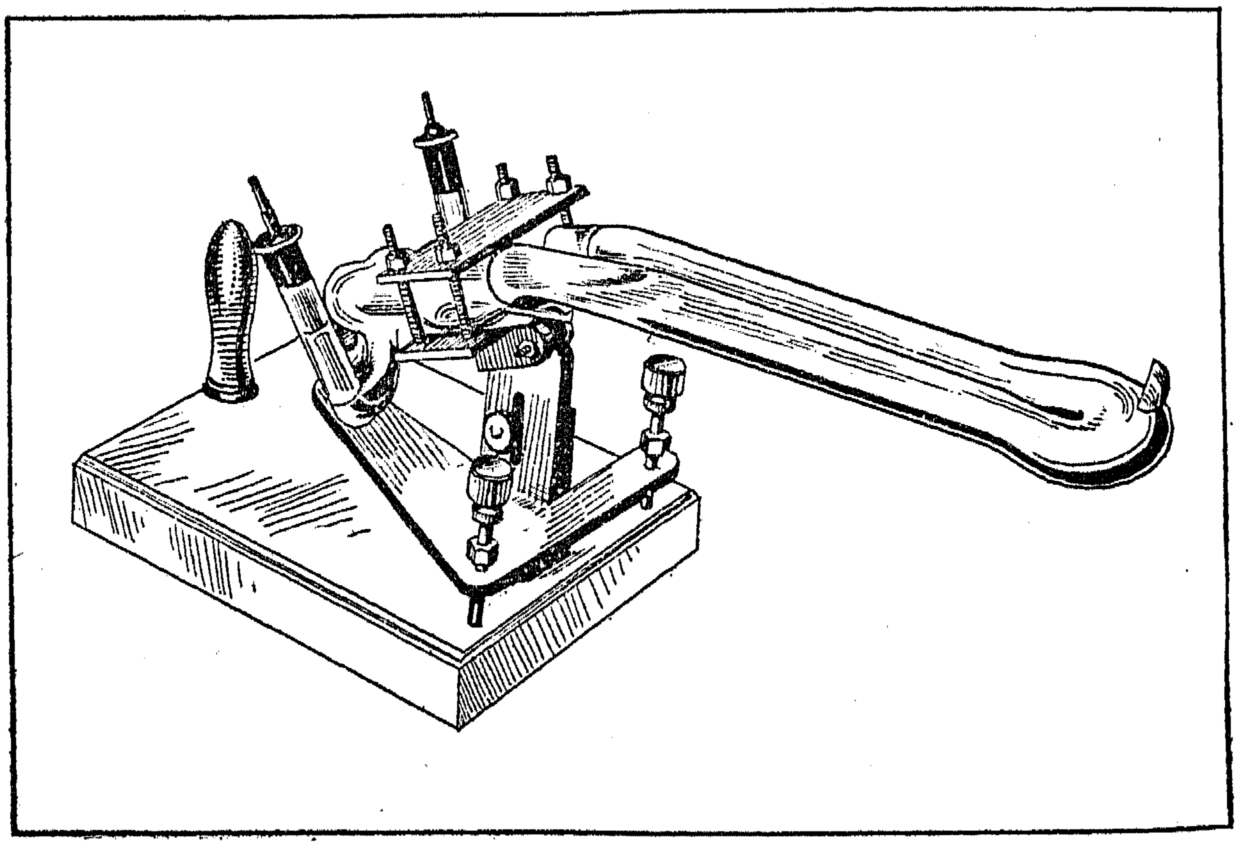

FIG. 10

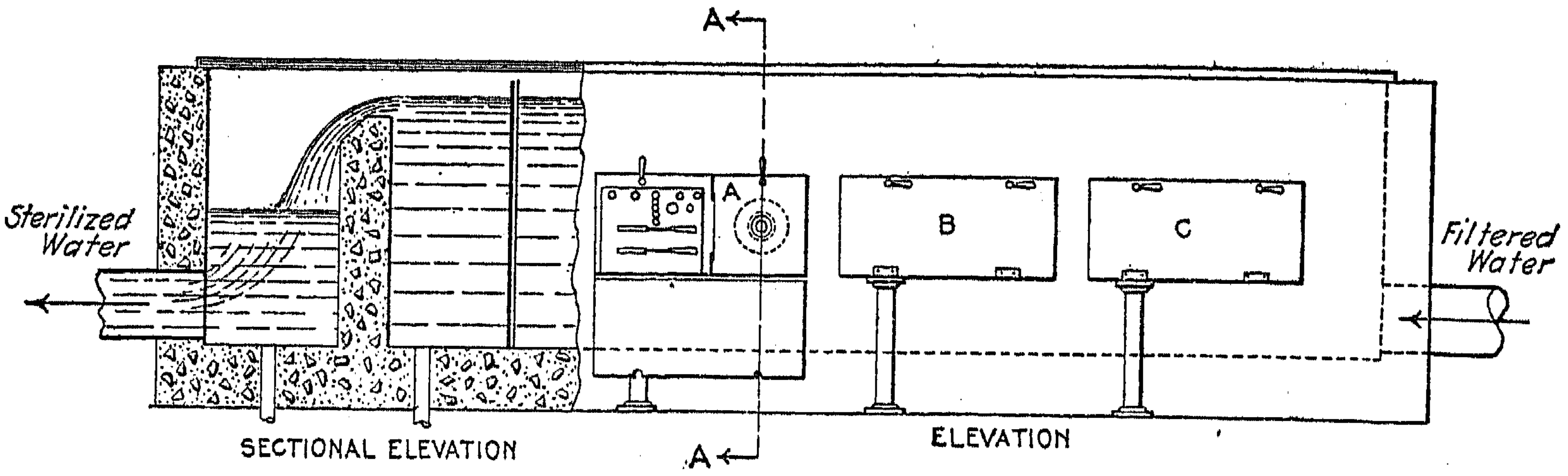

FIG. 11A

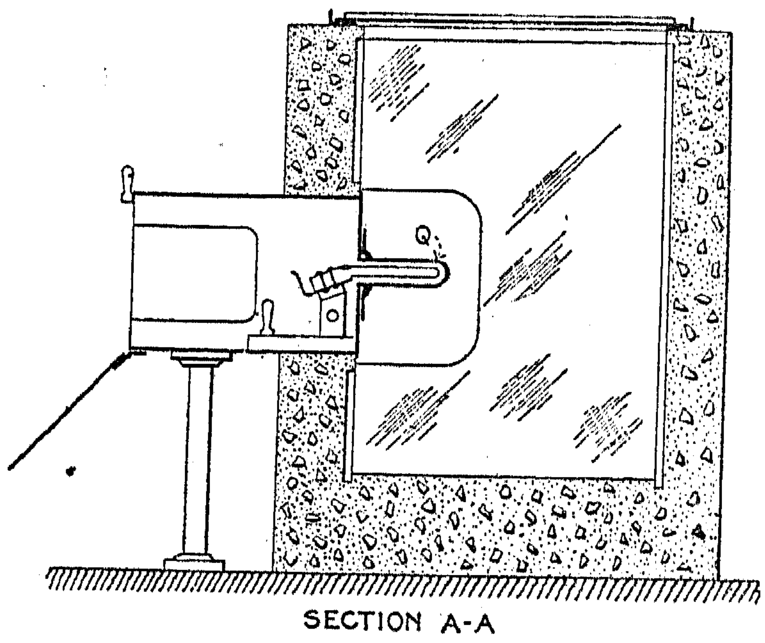

FIG. 11B

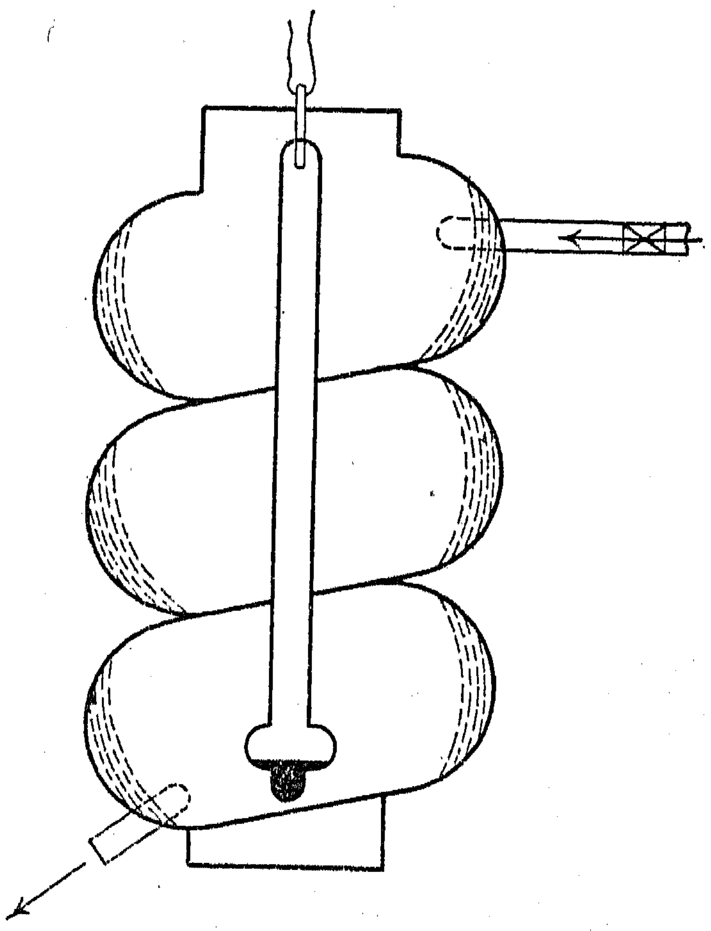

FIG. 13

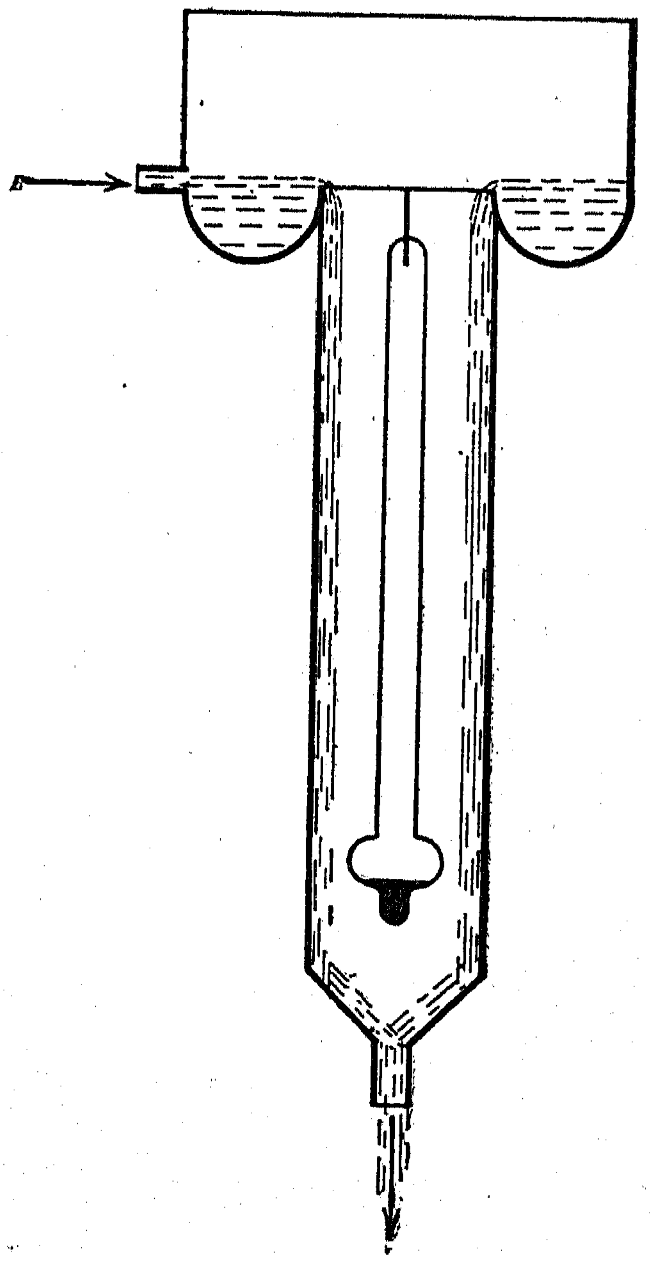

FIG. 12

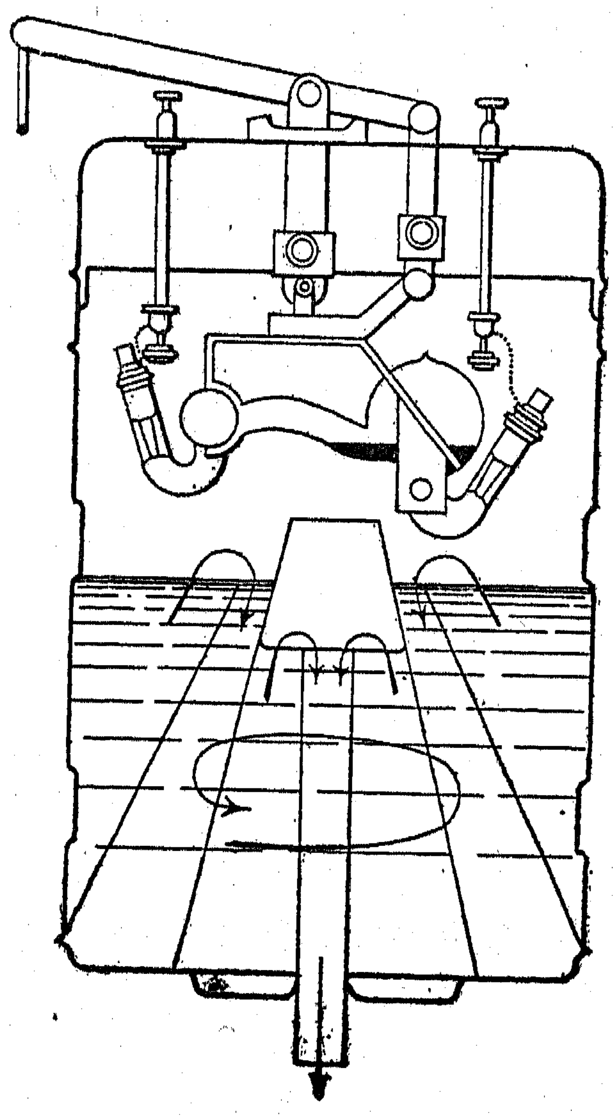

FIG. 15

getting into the illuminated zone, the condition for this being that no suspended matter is contained in the water which would form a shield for the germ.

Water for this sterilization has, therefore, in most cases to be filtered before being submitted to the sterilizing action of the rays. However, even very good filters will allow some microscopic matter to pass. It is much more effective, as shown by experiments, to stir up such water while it is going through the illuminated zone so as to turn over and over any particles which otherwise might allow microbes to pass by under cover. The baffle arrangements as shown in Figs. 14, 15 and 16 are built in for this purpose of stirring up the water. For the same reason,

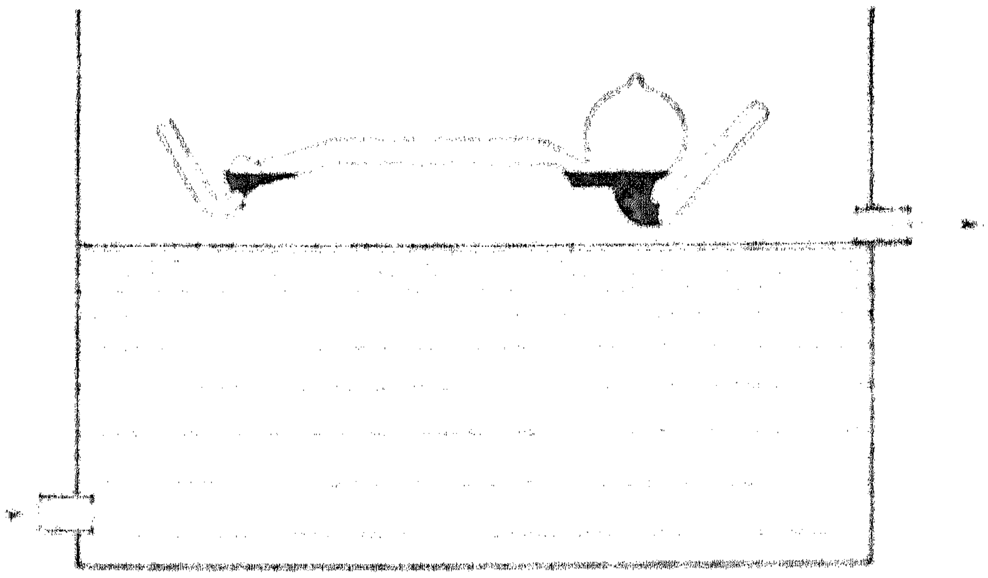

FIG. 14

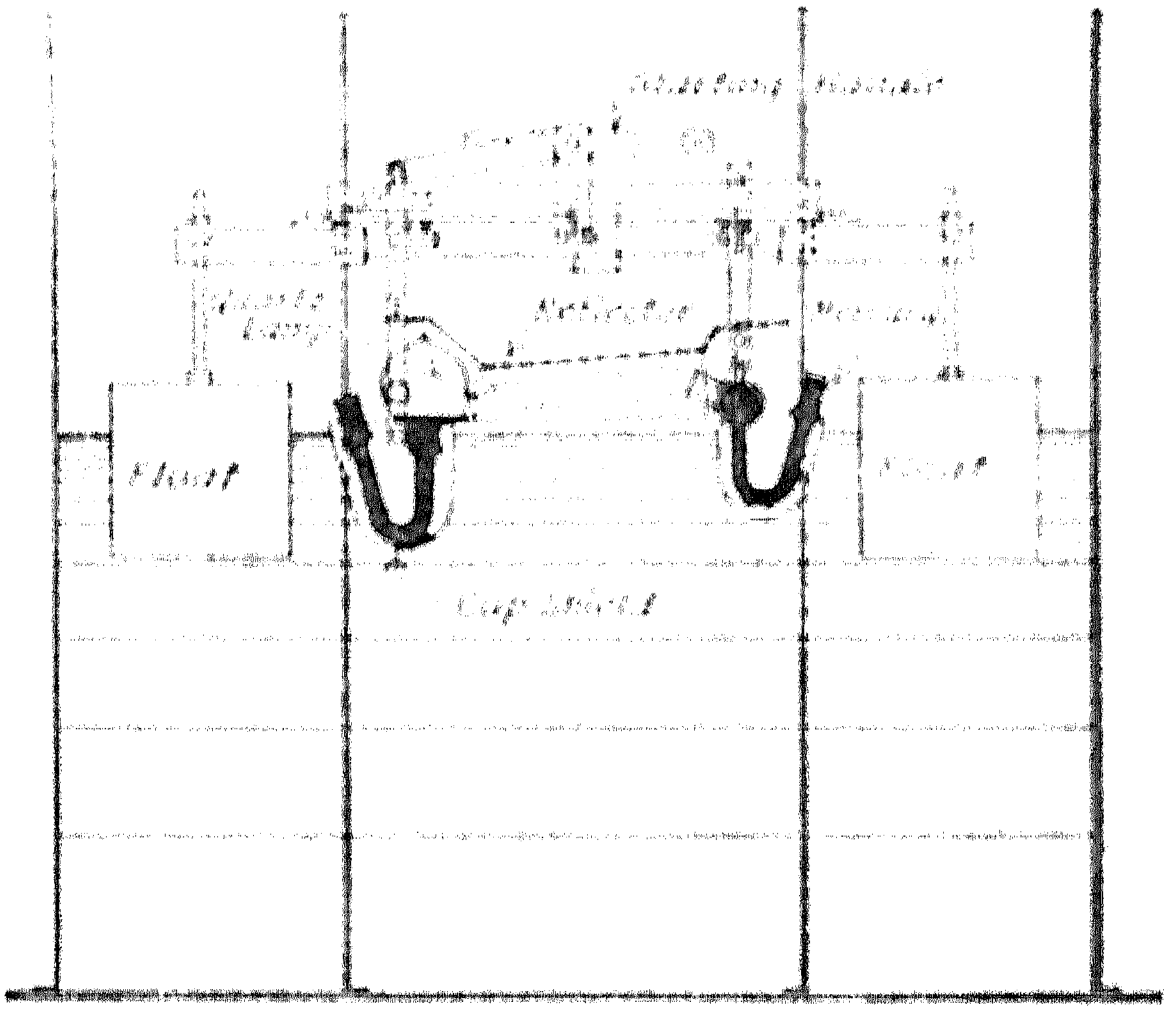

FIG. 16

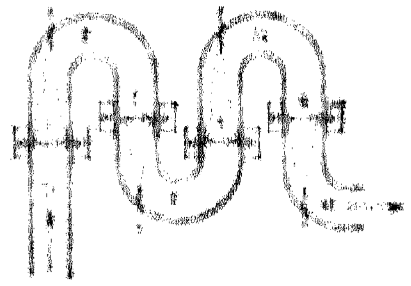

FIG. 16A

also, it is best to pass the water through several illuminated zones, which can easily be done by leading the water several times towards the same source of light (Fig. 15), or by passing it successively under several sources of light, as shown in Figs. 11 and 16.

TYPICAL INSTALLATIONS

The largest unit ever built (Fig. 18) was set up about two years ago in the city of Luneville, France, to sterilize the city water supply. It consists of a flume into the sides of which ten 500-volt pistol lamp equipments are inserted. These equipments consist of metal boxes for the starting of the lamps (the latest types of them contain also the rheostats). The boxes are equipped on the inside with a stuffing box arrangement holding the quartz protective tube which protrudes into the water (see Fig. 11B). The lamps are lit in the starting boxes and then their luminous parts are inserted into the protective tubes, so that the light emitted from the lamp enters the water.

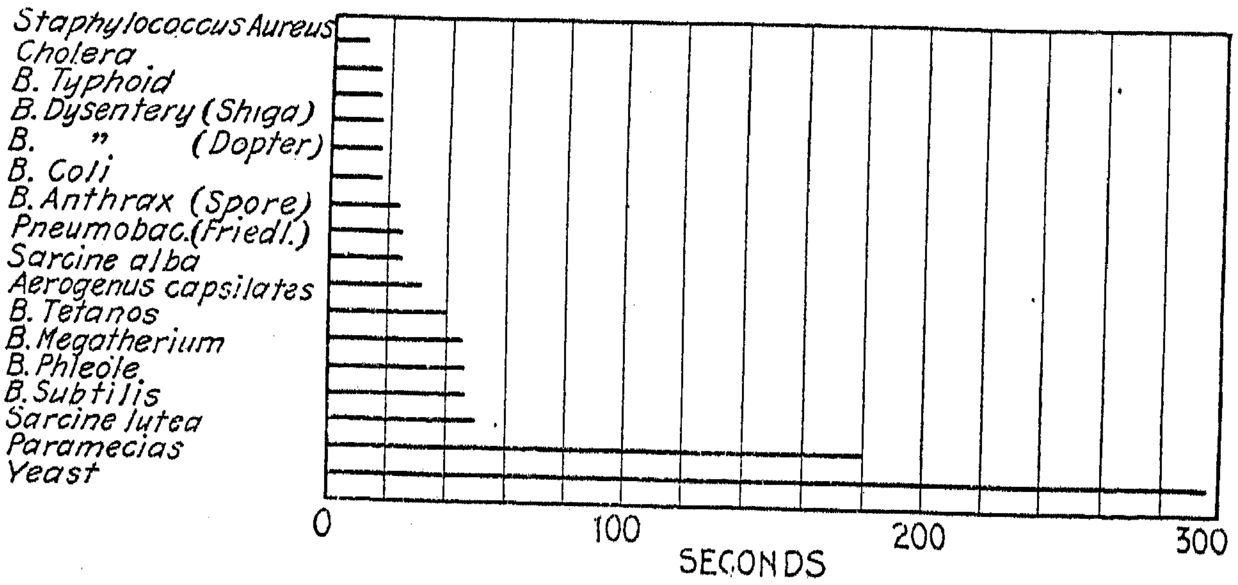

FIG. 17

The raw water fed into this plant comes from the Meurthe river and contains sometimes as high as 60,000 germs per cu. cm. It is clarified by a series of roughing filters and one filter. After this it is physically in fairly good condition, being very poor in suspended matter, but having from time to time fairly deep color (up to 45 U. S. standard) in solution. The germ contents are sometimes as high as 1000 per cu. cm. in this water. It is then passed through the sterilizing unit described above, coming under the influence of the light from one to two minutes altogether, according to the number of lamps running. This number (sometimes only 4) depends on the physical condition of the water, which is easily observed. The bacteriological tests of the water when leaving the sterilizer rarely show more than 10 germs per cu. cm. and are often zero. Bacterium coli is always eliminated. Not only are the bacteriological tests satisfactory; the health of the community has improved considerably. Typhoid used to cause from 70 to 160 deaths annually; it is now practically eliminated, there being no cases at all this year.

Another typical installation was made in New York lately for the purification of the water of a swimming pool, which is naturally exposed to continuous pollution from the bathers. The water in this case is circulated continually through a filter to take out suspended matter and then it passes through the ultra-violet ray sterilizer. This apparatus is similar to the Luneville unit except for its size, as it contains only two 220-volt pistol lamps. It is rated at 175,000 gallons capacity per day. Tests at the outlet of the sterilizer show only a few germs, and tests of the water going to the purifying apparatus have improved from 6000 germs per cu. cm. to about 350 germs per cu. cm. since the introduction of the ultra-violet ray apparatus.

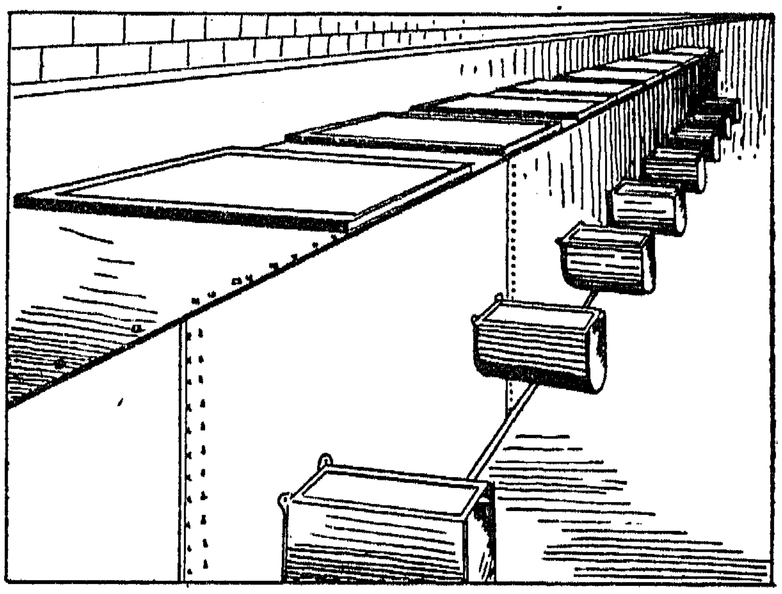

FIG. 18

CONSUMPTION OF ELECTRIC ENERGY

The smallest lamp used in the above apparatus operates at 110 volts with two amperes. The largest made so far is for 500 volts, 2.5 amperes. The largest apparatus built contains ten of the last-mentioned lamps. The power consumption in such a case, with a very large safety coefficient for the sterilization, is between 50 and 130 kw-hr. per million gallons of water. This amount of power is evidently not very great but it will always do something to smooth out the load curve of a power station, as, in most cases, such apparatus will be operated continuously. Many installations of this kind have been made in Europe for both small and large water-works, and they are operating very successfully. Their simplicity and rapidity of action are highly satisfactory.

DISCUSSION ON "STERILIZATION OF WATER BY ULTRA-VIOLET RAYS OF THE MERCURY-VAPOR QUARTZ LAMP" (VON RECKLINGHAUSEN), DETROIT, MICH., JUNE 26, 1914.

Morgan Brooks: I notice one point, that is not of very great importance, that perhaps might lead to error. The author speaks of the light varying inversely as the square of the distance. That is true in the case of point source, but not true of line source. If the light is of any appreciable length in proportion to the tank, or the vehicle which is used in conveying the water, it will vary more nearly in inverse proportion to the distance, which will make a difference in some cases.

Theodore A. Leisen: The question of water purification is assuming such an important aspect throughout the whole country that any system of this kind will be welcome to all engineers interested in water supply. There are a few questions I would like to ask in regard to the result; first of all, as to the effect of a certain degree of turbidity of the water on the results of sterilization through the ultra-violet rays, and also the effect of color in the water; in other words, the ratio of increased consumption of current due to the increase in the turbidity of the water. My reason for asking that is that the question will come up as to the applicability of this system to waters where filtering may not be considered necessary as a means of clarification. I think that is notably the case in Detroit, at least as far as my experience goes. The water is reasonably free from turbidity, the actual turbidity scale running about 10 to 30 parts in the million, and for clarification purposes filtration would not really be necessary if a sterilizing medium could be applied that would act without the necessity of filtering in advance. I do not know what the turbidities go up to here in certain times of storm, in the case of the lake water, possibly too high to apply it without previous filtering. The water here is free from color, so that the color question would not enter into the discussion, except as a general matter of information. Dr. von Recklinghausen has said that, unfortunately for the power plants, the amount of current is very small; of course, that acts inversely, as far as the water department is concerned—the less current we have to use for sterilizing purposes the better satisfied we are. Our interests are not always identical.

From the commercial point of view the ultra-violet ray method of sterilization will have to come into competition with the use of certain chemicals, notably, calcium hypochlorite, which is being used extensively at the present time, and used very successfully. If, however, we can substitute a system of the kind described here, it will be very well, for the reason that it does away with all legitimate objections to any mixture of chemicals into the drinking water supplied. The use of hypochlorite of lime will unquestionably produce satisfactory results, so far as elimination of bacteria is concerned. If it is used in too large quantities, it is likely to impart an odor and possibly a taste to the water, which is objectionable, and from the esthetic point of view, if from no other, the ultra-violet ray would be far more satisfactory than the hypochlorite of lime, but, from the commercial point of view, one must compete with the other, to a certain extent; and it would be very interesting from the water-works man's point of view, at least, to get some definite figures as to the actual cost per million gallons of water sterilized by means of the ultra-violet rays.

I believe that almost any city would be willing to spend a little more money in the cost of operating a plant to sterilize the water by means of ultra-violet rays than it would to sterilize the water by means of hypochlorite of lime, or any other chemical agent, but if the diffierence is too great, it is always going to be a question which system will be adopted. Here in Detroit the question will come up for consideration very soon. The matter of filtration has been discussed more or less during the last few years, and I assume that one of the problems which will devolve upon me to settle is whether we are compelled to put in a filtration plant or not. If we could substitute a system of the kind described, in place of the filtration plant, it would be a great advantage to the city and probably result in considerable economy. If the filtering plant is necessary in the first instance, it might be a question whether a sufficiently high degree of purity could not be obtained by filtering alone, without resorting to ultra-violet rays at all, although it is an admitted fact that no filtering gives absolutely pure water. On a percentage basis, we can show beautiful results, and on a practical basis we show good results. The average mechanical filter, assuming aluminum sulphate or sulphate of iron is the coagulating medium, will in almost every instance give a reduction of from 99 to 99.9 per cent, which is almost as near absolute purity as you are likely to get under ordinary conditions. The chart referred to here, showing the reduction in typhoid fever cases, is an interesting one, and one along the same line was shown by us. I would like to ask whether during the preceding years, 1908 to 1912, filtration alone was in use in that city, or whether they used raw water—in other words, when the filter plant was first started, in distinction to the time when the ultra-violet ray system was started.

If Dr. von Recklinghausen can give any figures as to cost, I am sure they will be very interesting to everybody concerned in the subject of water supply.

William B. Jackson: I wish to ask whether the sterilization by the ultra-violet ray does not come into direct competition with the sterilization by ozone, the same as it does with sterilization by chemicals; and if so, whether Dr. von Recklinghausen can give us any idea as to the relative cost of sterilization under the two conditions of operation. I would also be interested to learn whether there is any definite understanding of the physiological effect of the ultra-violet rays upon the germs, that is, whether the germs are supposed to be killed by heat or poison, or what the effect may be.

M. von Recklinghausen: Regarding the variation of the power of light, I can state that the law of the square of the distance holds about true, although some absorption of light in the air has to be added, also correction has to be made for the line shape of the lamp.

To the interesting remarks of Mr. Leisen, who is one of the foremost water experts in this country, I would like to reply as follows: If turbidity consists of particles which are bigger than a microbe, it might shield the microbe. If turbidity particles are smaller than the microbe—for example, as in the case of the Mississippi water—I do not think they will shield it. I think that such very fine turbidity will act like a color in solution, that is to say as an absorbent, and reduce the abiotic action, at a certain distance, to a certain degree, which can be determined very closely. In my experience, very fine so-called colloidal clay in water acts just like color in water. We have worked with such turbidities up to twenty parts per million, and have had about as good sterilization in that case as in working with low turbidities.

This was worked out in a very small plant, so I am unfortunately unable to indicate the amount of power which this amount of turbidity would need on a large scale. If turbidity consists of coarse suspended matter, I believe it will depend on the size and character of this suspended matter whether it will handicap sterilization or not. It will surely shield some microbes, but it is most likely that these microbes, due to the stirring action of the sterilizer, will at some other moment not be shielded when passing through the illuminated zone, and will therefore be killed.

Let us take another case, of very heavy particles—suppose we take the effluent from a sewer; it is most likely that visible particles flowing in the sewer water will themselves be full of microbes and heavily infected inside. I think it is out of the question that the rays will strike, during a few seconds' exposure, the microbes hidden in the inside of such particles, and I think, that, *a priori*, heavy floating particles handicap sterilization if those particles are themselves polluted and contain germs. The light must be able to strike the microbe at its first, second or third, etc., passage through the illuminated zone. If that microbe is hidden every time it passes through the light it is not killed.

I understand that here in Detroit the turbidity of the water which is taken from Lake St. Clair right near Belle Isle is usually pretty good and does not show turbidity much higher than 10 most of the year. I understand that, however, during certain storms, the silt at the bottom of Lake St. Clair, which is pretty shallow, is stirred up and the turbidity is very high—I am not sure of the figures, but understand it is 250 parts per million—

that it is practically like coffee. I am certain that such water could not be directly treated with ultra-violet rays, because they would penetrate only a few millimeters, and after that they would surely be held up by either one or the other of these particles. Therefore, I think in a case like Detroit it seems to be necessary to filter the water at least during some months of the year, but possibly during ten or eleven months it need not be done.

Now, as to the question of competition—and this will be partly in reply to Mr. Leisen's question, also—I know that hypochlorite of lime is used to disinfect the water, and I think it will always be a little cheaper to take a barrel of hypochlorite of lime and stir it up with water, and drop it into the drinking water. I have no doubt about that, but you must consider that in the case of a waterworks plant, particularly a small waterworks plant, you cannot do this unless you have a chemist, or some expert, following the matter of addition of these chemicals to the water right along very carefully, so as to avoid giving the water a bad taste or imparting an odor to it. I think that you will find the application of these disinfectants will come pretty high if you include the amount of intelligent labor necessary to follow such applications. Besides, we have to consider the objection on the part of the public to the use of obnoxious chemicals in its drinking water.

In reply to Mr. Leisen's remarks regarding the cost of treatment per million gallons, it will depend on the original condition of the water. The waters which I have seen coming from the modern mechanical filters are of such an ideal physical purity, that is to say, there is such a decided absence of suspended matter and color, as I have never seen in waters in Europe. If the physical condition of the water is as perfect as this, I am persuaded that—although, of course, I could not say I could guarantee it—it would be hardly necessary to use more than 30 kw-hr. per million gallons to do the work, and if you use 50 kw-hr. per million gallons, as I stated in the paper, you have a safety coefficient which I think it is desirable and even imperative to have in hygienic work. I do not know what a kilowatt-hour can be made for, but call it one cent, then 30 cents per million gallons would probably be sufficient. There is another expense to be considered—that the lamps have to be renewed from time to time. I doubt if this will come to more than just the same sum, so that I think the total cost would be about 60 cents per million gallons. Now, in the case of chemicals, with all the intelligent supervision, etc., the cost may be a little less, but, as Mr. Leisen said, I do not think it is a question merely of dollars and cents, but a question of giving decent water to the public, and even if the total cost should run a few cents higher, I do not think a modern city would hesitate to do something for the welfare of the people and deliver always decent water.

I have not yet been able to get a plant running in this country in connection with one of these modern mechanical filters, which give, according to my laboratory tests, such ideal and perfect conditions. It may be, therefore, that the figures of consumption I give are somewhat exaggerated.

Regarding the typhoid records in Luneville, France, up to 1911 they used spring water, without purification. In 1912 they started to filter the Meurthe River water, and added spring water to it, using practically 90 per cent of the river supply, and there was some falling off in typhoid cases at that time, as you see from the chart, due to the mere filtration of the water, at the rate of seven million gallons per acre, with some previous roughing. The fact that the typhoid cases have gone down to zero, since sterilization was applied, I think is due to the fact that sterilization does not let any coli, the indicator of germs of intestinal diseases, get through at all. I know that hygienic statistics have to extend over ten years to be really reliable, and you have to get statistics from many places. I am sorry that our industry is too young to give ten years' tests, and I can only give you those which I have at my disposal.

I have another case of a small plant which I showed you on the screen, where the same results were obtained; typhoid is prevalent all around that country, which is a suburb of Rouen, France. All round they used the same kind of water, and there was a good deal of typhoid in that district. Since the sterilizing plant has been put in there has not been a case of typhoid for two years—as the statement, which I have from the Health Office of the town, shows.

Now we come to the question of competition from another source—ozone. Ozone has not been used much in this country. It has been used to a certain extent in Europe to act as a sterilizing agent, and I think difficulties are encountered, not so much on the question of whether ozone sterilizes or not, but on the question—Do you produce ozone or do you produce something else? It is known that a slight amount of humidity in the air which is subjected to the ozonator, will produce something else than ozone, namely, nitrous acid, which is not a sterilizing agent, and therefore the results of the plants which are in actual service prove rather discouraging from the bacteriological point of view. From the economy point of view, I would only refer to one set of tests, which were made by the Aquedotto Nicolai in Genoa, for about six months. This trial plant supplies about a thousand tons of water per day, and the water was treated alternately by ultra-violet rays, and by an ozone plant. The current consumption was practically the same with the ultra-violet rays plant and the ozone plant, but in the latter case only so far as the ozonator was concerned, not counting the cost of moving the water to the ozonator and the cost of forcing the ozonized air through the water. Taking it altogether, I think the power used is less with the ultra-violet rays. In the case mentioned, the report says that the ultra-violet rays can be run by a little girl, while the ozone plant needs an engineer.

William B. Jackson: What is the relative first cost of the plants?

M. von Recklinghausen: I cannot tell you the relative cost of the plants, as I do not know the cost of the ozone plant. I know in this case—I suppose they are all different—the original cost was 2.5 times as much, but I do not know whether that would account for all costs. I do not want to give that figure as the real figure. What is needed is the machine necessary for ozonizing, the high-frequency alternator, high-frequency transformer, and then the maintenance of the dielectrics, which blow out from time to time, etc.

William B. Jackson: Does the ozone work better on muddy water?

M. von Recklinghausen: There is one thing strange about practically all sterilizing agents, and that is that they all must be used only on practically clear water. In the case of ultra-violet rays, there is the physical necessity of having the rays strike the microbes. In the case of any chemical sterilization like ozone or hypochlorite of lime, you need much more of the chemical, in the case of the water being muddy, than when the water is clear. I think that is because some of the sterilizing—that is, the oxidizing—agent is used up by the organic mud, and you need much more ozone, etc., to penetrate into the organic matter than if such floating matter or even organic matter in solution is absent.

The last question asked was: what the real effect is. Like many biological things, we do not know. If you expose water for a long time to ultra-violet rays, you might get a slight amount of peroxidation therein. This so-formed disinfectant could not, however, account for the sterilizing action of the rays, owing to the short period of time that the rays act on the germs. The amount of hydrogen peroxide generated by the light shining on the water is perhaps one millionth of what would be needed to produce enough peroxidation to act as a sterilizing agent. If we submit a germ to the ultra-violet light and look at it under the microscope, after having exposed it for a long time, we find its plasma coagulated, therefore many will say that the action is coagulation of the plasma. After just enough exposure to ultra-violet light, however, the germs appear to be identical with living ones, except that their motility has gone. I think the exposure necessary, for instance, under the pistol lamp, to kill the bacteria, is one-twentieth of a second. I doubt whether you can make a complete chemical change in that microbe during that short time.

Alfred Herz: Is the microbe permanently killed, or only stunned?

M. von Recklinghausen: Permanently killed.

Alfred Herz: Any record of that?

M. von Recklinghausen: I need only mention the many tests made in Europe on plants for getting sterile water for surgical work. They want water which has no microbes, and they make a very strict test, which consists in taking 100, 200 or 300 cu. cm. of the sterile water and mixing it with sterile broth. They put these samples under the most favorable temperature conditions for the microbes to develop. After several weeks, if the microbe contained in that broth has not developed, they come to the conclusion that it is dead, and such results have been obtained over and again with water which had been freed of its often very rich content of germs by short exposure to the ultra-violet rays.

A. E. Walden (communicated after adjournment): For nearly seven years the writer has been experimenting with ozone gas for sterilizing water, and for a shorter period with the ultra-violet ray, and noting the interest in the paper on the ultra-violet ray, as evidenced by the published discussion, believes that further information would be of value.

The sterilizer we are operating in Baltimore has a capacity of four million gallons daily, and has been operating more or less satisfactorily for several years. We also procured in Europe an ultra-violet ray sterilizer for experimental purposes, it being the first, in our belief, to be used for this purpose in this country.

Now, it should be stated that both the ultra-violet ray and ozone apparatus have distinct fields, but that ozone will do work that ultra-violet rays cannot do, with the knowledge we have of both today. The ultra-violet ray has no action on algae, or amorphous matter, or color, while ozone has, although both reduce bacteria. Again, ozone will purify water without previous filtration, while the ultra-violet ray, to be most effective, must have a water low in turbidity.

Ozone sterilizing apparatus, including roughing filter (for use during times of high turbidity), can be constructed for $6,000 to $7,000 per million, in 5 million gallon units or over, and the total operating cost will be approximately $2.50 per million gallons, or under, allowing for local conditions.

A question was asked by Mr. William B. Jackson as to the relative merits of ozone and ultra-violet ray on muddy water (high turbidity), and it may be said that ozone is far and away superior to the ultra-violet ray under this condition in so far as we have knowledge today, and that with the ultra-violet ray with a water having a turbidity greater than 10 the manufacturers will not guarantee results. However, our experience with this system shows that the rays will satisfactorily penetrate turbidities of 20.

The cost of the lamps is excessive, and they are very fragile and easily affected by handling.

To get back to European results by either method, I want to state that they cannot be applied to conditions in this country, neither are they correct as we require them.

I submit herewith a short table of results at our plant, which we can and expect to improve on in our proposed new plant.

TABLE OF OZONE RESULTS
STERILIZING THREE MILLION GALLONS DAILY

Bacteria removed......................73 to 99 per cent.

At the same time removing as follows:

	Algae	Amorphous Matter	Color
Maximum.....	79%	80%	15 to 45%
Minimum......	9%	11%	
Average.......	40%	50%	

Requiring from 60 to 90 kw-hr., or 2 to 5 kw. per million.

TABLE I—RESULTS OBTAINED FROM OZONIZERS AT HERRING RUN UNDER VARYING CONDITIONS (3,000,000-GAL. UNITS).

Bacteria per cu. cm.			*B. Coli* presumptive test		Color (parts per million)			Turbidity (parts per million)		
Raw	Ozonized	% Removal	Raw	Ozonized	Raw	Ozonized	% Removal	Raw	Ozonized	% Removal
4300	31	99.2	*4/4	0/24	65	30	53.8	40	40	0.0
1800	53	97.0	4/4	0/24	25	18	28.0	12	12	0.0
2080	25	98.7	1/4	0/24	25	20	20.0	18	18	0.0
1810	31	98.7	4/4	2/24	25	16	36.0	18	18	0.0
2300	79	96.6	0/4	0/4	28	18	31.7	20	20	0.0
146	18	87.6	1/4	0/4	24	21	16.3	8	8	0.0

*4/4 = 4 positive presumptive tests out of 4 one-cu. cm. samples tested.

TABLE I—(*Continued*)

RESULTS OBTAINED FROM OZONIZING WATER, NOVEMBER, 1909.

	Bacteria per cu. cm.		*B. Coli*		Color		Turbidity		Alkalinity	
Date	Raw	Ozonized	Raw	Ozonized	Raw	Ozonized	Raw	Ozonized	Raw	Ozonized
Nov. 3	3200	12	4/4	0/8	20	14	18	18	25	25
" 4	2700	6	2/4	0/8	22	15	20	18	26	26
" 5	1960	6	2/4	0/8	25	17	20	20	26	26
" 12	1300	12	4/4	0/4	24	14	18	18	25	25
" 12	1300	18		0/4	24	14	18	18	25	25
" 12	1410	15		0/4	24	15	18	18	25	25
" 12	1390	16			24	14	18	16	25	25
" 13	1920	54	3/4	1/4	23	17	20	20	25	25

TABLE I—(*Continued*)
RESULTS OBTAINED FROM OZONIZING WATER, NOVEMBER AND DECEMBER, 1909.

	Bacteria		*B. Coli*		Color		Turbidity	
Date	Raw	Ozonized	Raw	Ozonized	Raw	Ozonized	Raw	Ozonized
Nov. 24	5100	*810	4/4	3/4	25	20	25	25
" 26	2520	*650	2/4	2/4	22	18	20	20
" 27	1800	*740	4/4	1/4	22	17	23	23
" 29	2420	9	1/4	0/8	20	8	18	18
Dec. 2	3680	6	4/4	0/4	18	10	18	14
" 3	1420	13					14	14
" 4	1100	4	1/4	0/4	18	10	16	16
" 7	1240	6	1/4	0/4	21	15	15	12

*The results on Nov. 24th, 26th and 27th show the effect of ozone on water containing a great amount of organic matter. During these days a piece of straw braid was suspended in the mixing chamber of the ozonizer. The braid was removed on the 29th, with the improved bacterial results indicated.

TABLE II—RESULTS FROM 3000-GALLON OZONE APPARATUS (DOMESTIC STERILIZER).

Bacteria per cu. cm.			*B. Coli*		Color			Turbidity			Oxygen required		
Raw	Ozonized	% Removed	Raw	Ozonized	Raw	Ozonized	% Removed	Raw	Ozonized	% Removed	Raw	Ozonized	% Removed
2460	26	98.95	present	not found	22	5	77.28	20	20	00.0	1.55	0.60	61.30
2800	12	99.58	"	"	30	15	50	40	40	00.0	1.40	0.85	39.19
1100	5	99.55	"	"	17	0	100	15	15	00.0	1.15	0.55	52.18
1270	6	99.53	"	"	35	15	57.15	15	15	00.0	1.47	0.85	42.18
1200	0	100	"	"	12	0	100	17	17	00.0	1.15	0.70	39.13
59000	680	98.85	"	"	65	40	38.46	400	400	00.0	3.75	3.10	17.34

TABLE III—RESULTS FROM 3000-GALLON ULTRA-VIOLET RAY APPARATUS

Bacteria per cu. cm.						Average efficiency	*B. Coli.*				Parts per million				Volts	Amperes
Raw	Sterilized						Raw		Sterilized		Turbidity		Color			
	1	2	3	4	Average		Tests made	Tests positive	Tests made	Tests positive	Raw	Sterilized	Raw	Sterilized		
450	2	0	0	2	1.0	99.78	4	0	16	0	20	20	22	22	80	4
580	7	4	6		5.6	99.04	4	1	16	0	14	14	16	16	80	4
1390	5	2	0	4	2.7	99.81	4	2	16	0	15	15	14	14	80	4
310	8	4	2	0	3.5	98.78	4	3	16	0	12	12	10	10	80	4
490	4	6	6	2	4.5	99.09	4	2	16	0	18	18	12	12	80	4
210	0	0	4	2	1.5	99.29	4	0	16	0	20	20	12	12	80	4
600	0	0	0	1	0.2	99.97	4	1	16	0	16	16	10	10	80	4
720	4	2	0	3	2.7	99.63	4	2	16	0	15	15	8	8	80	4

Rise in temperature on the case of the sterilizer directly above the lamp.

Time	Start	5 min.	10 min.	15 min.	20 min.	25 min.	30 min.	35 min.	60 min.
Degrees Fahrenheit	80	94	142	180	194	206	208	210	210

Regarding the ultra-violet ray lamp, the quartz tubes give good results at first but in a short time become defective, due either to failure of seal or to a film of oxide on the tube inside.

In European practise the current consumption with filters and an effluent of low turbidity is from 36 to 140 kw-hr. per million gallons, the filters passing from 90 to 120 millions per acre per day. Water that has a turbidity of 45 parts per million cannot be sterilized satisfactorily. The maximum depth of water which has been sterilized is about three feet, and if this is reduced to one foot the approximate time might be said to be reduced in proportion to the effect of light rays; in other words, if the lamps sterilize at a depth of one foot at the rate of one second, when the distance is doubled, or at a depth of two feet, the time of required exposure will be about four seconds, but may vary 5 to 10 per cent.

The time of exposure runs usually from 50 seconds to 1½ minutes, but where the effluent is very low in color and turbidity, as from mechanical filters using sulphate of alumina, a period as short as 10 seconds will answer for effective sterilization, but is not to be recommended for safety under operating conditions.

The life of the lamps is guaranteed at about 3800 hours, and in testing to see if the ray efficiency (consequently the bacterial efficiency) is maintained, it appears that the lamps are tested at a distance of 50 cm. with solio paper, and if the paper turns pink in approximately 10 seconds the lamps are considered all right, but if it requires 15 seconds, or more, there is some question as to their efficiency and they are removed for further test. It should be noted that there is no satisfactory method devised for the control of the lamps in operation to tell accurately when any have deteriorated, and just how fast they are deteriorating, which makes operation uncertain, and the system will require more technical supervision for this reason.

We have had considerable trouble with lamps blackening, or mercury oxide.

There is no change in the organic matter, as there is with ozone, and as before stated, the time and depth will probably vary 10 per cent. The efficiency will be higher with the higher voltage lamps requiring 400 to 500 volts.

With ozone gas, climatic conditions affect the operation, although this has been practically eliminated; and then there are troubles from punctured dielectrics, the expense of renewing these, however, being small.

This gas will alone remove the major portion of the algae and organic matter, and reduce the color from 15 to 40 per cent, and at the same time remove from 73 to 99 per cent of the bacteria, but if the organic content is high the reduction is high and the bacteria reduction is lowered, but as we become more familiar with these conditions they will be removed or improved.

A test for ozone can easily be made, and an approximate determination of the strength made by passing a given quantity through iodide of potassium solution, and we have proved by many hundreds of tests that at no time has it been possibe to detect nitrous acid, and further, that the removal of the algae and organic matter causes the bacteria to die in the mains, and it is believed that this is due to the removal of the organic matter necessary to maintain bacterial life.

It might be stated that all forms of bacteria are really vegetable micro-organisms; also that there are some 60 gas-forming bacteria; and it is not possible to determine the *Coli* other than in a presumptive manner (except by special plating requiring a period of time too long for the purpose. We have further found, in testing for bacteria in air, that from one cu. cm. taken from a solution made from one square inch taken from the air filter and distilled water, there were 9000 gas formers, or presumptive *B. Coli*, out of a total of 27,000 bacteria, which goes to show, we believe, that ozone gas will eventually prove of value for air purification, as soon as its action and method of handling are better understood.

For those seeking further information on this subject there will be found papers in the *Proceedings* of the American Works Association of 1911, also papers by the chemist of the Baltimore County Water and Electric Company, Mr. Sheppard T. Powell, in the *American Water Works Journal* of September, 1914, and also Dr. von Recklinghausen's paper of the same date.

It is our belief that both these sterilizing agents will find a field in both water and sewerage treatment, and particularly in the treatment of the discharge from tanks of the Imhoff type, as evidenced by our experiments.

It may be added that the ultra-violet ray has recently been tried in Baltimore for sterilizing milk, and the result was that a decided offensive taste was imparted to the milk, which would prevent the use of this agent for this purpose. Further, milk sterilized with ozone will not give up the characteristic taste of the gas used, as it seems to be retained in the milk. However, rancid butter can be renovated without any apparent effect on the substance itself.

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A HIGH-SPEED PRINTING TELEGRAPH SYSTEM

BY CARL KINSLEY

Abstract of Paper

The paper describes a system of high-speed printing telegraphy devised by the author, a prominent feature of which is the simplicity of the apparatus and its operation. The author briefly mentions a number of high-speed systems which have been tested by the operating companies, none of which have completely fulfilled all the requirements for accuracy, rapidity and low cost which are desirable for commercial work.

The system described is operated in connection with a commercial typewriter to which a punch is connected which perforates a half-inch strip of paper with groups of holes distinctly spaced in five rows, each group representing a letter. The punched strip of paper is then sent through the transmitter so that the holes pass under five wire brushes. Batteries of either polarity are thus connected between the earth and either one of a pair of conductors, or batteries of different potential can also be used. At the receiver there are five elements which are separately controlled and these elements make an autographic record by means of a local battery on a moving sensitized paper whenever they touch the surface. The apparatus, which is comparatively simple, is illustrated and described in detail. On the basis of simplex working and the use of two wires, the operating speed is 650 words per minute over a 375-mile line. If duplex working should be used the total speed of working per wire would be increased accordingly.

THE RATE of increase in the amount of business transacted by telegraph has been most marked during the past few years. The extension of the network of telephone wires and their universal use in local business has seemingly stimulated the desire for a formal method of inter-communication which is more rapid than the mails.

The operating companies have responded as fully as they could, with the means available, to the public demand for a more rapid, accurate and inexpensive service. They have carefully tested many systems of telegraphic transmission that have been presented to them. None of the systems, however, has fulfilled all of the requirements for accuracy in the transmission of the messages, rapidity of operation from the receipt of the message to its final delivery, and low cost; the latter includes, in particular, interest on invested capital, depreciation of telegraphic apparatus and lines, maintenance of plant and cost of operation.

It is impossible adequately to mention in the brief space available the telegraph systems which have already been tried, some of which have by no means been discarded. Among them the following may be of particular interest.

The Rowland multiplex printing telegraph system[1] has enjoyed a limited use in Italy and was experimentally operated on commercial business for a considerable time in this country. On the basis of eight machines operating simultaneously over two wires a speed of 400 words per minute could be obtained.

The Murray printing telegraph[2] was given a commercial test in America in 1900 and later taken to England where it was developed to a much more perfect state in the laboratories of British P. O. Department. It has recently been given a month's trial in this country. Used duplex with four machines working on the two-wire circuit and with eight automatic translators, a speed of 400 words per minute can be reached.

The Baudot printing telegraph[3] has been extensively used in France and India, while recently its use has been spreading to Great Britain, where certain improvements have been added. On the basis of duplex working, and using two wires, 160 words per minute can be transmitted.

The Siemens-Halske rapid printing telegraph system[4] has been remodelled from the system developed and extensively tested about 1903, which used a photographic process of recording. In its present form it has been successfully used on certain German lines and is being tried over three or four different circuits at the present time. It seems to be specially suited for underground cable work, as the speed of each instrument is low and the required perfect control of both synchronism and phase of the transmitter and receiver is then not affected by atmospheric conditions. The necessity for an entire absence of disturbance can be comprehended when it is noted that many letters require the operation of seven relays to switch circuits in the through line in preparation for each record. On the basis of duplex working and the use of two wires a speed of 400 words per minute is obtainable. This is only half as fast as the early form which required the developing, fixing, washing and drying of the record of the receiving message and thus produced a condition at the receiving end which was considered uncommercial.

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[1] G. Robichon, " Le Telegraphie Rowland, " *Journal Telegraphique*, Jan. 25, 1901 and Feb. 25, 1901.

Potts; *The Rowland Telegraph System*, A. I. E. E. TRANS., 1907, Vol. XXVI p. 507.

[2] Vansize; *A New Page Printing Telegraph*, A. I. E. E. TRANS., 1901, Vol. XVIII, p. 7.

Murray; " Practical Aspects of Printing Telegraphy, " Inst. Elec. Eng. *Jour.* v. 47, p. 450, 1911. See also *Electrician*, May 5 and 12, 1911.

[3] " D'Appareils Baudot," Poulaine and Faivre, Paris, 1906.

Williams; " The Baudot Telegraph System in India," *Electrician*, Mch. 22, 1907.

[4] Franke, " Der neue Schnelltelegraph der Siemens und Halske," *Elektrotechn. Zeitschr.*, Sept. 25, Oct. 2 and 9, 1913.

The Pollak-Virag writing telegraph system,[5] unlike any of the preceding, does not require synchronism between transmitter and receiver. The received message, however, is photographically recorded on a sheet, which process entails expense and delay in handling the message. It was given an extensive commercial test over German lines and also was exhibited in England and in this country in 1899. On the same basis as that used in the tests of the previous systems the Pollak-Virag telegraph operated at 650 words per minute.

The system about to be described does not employ synchronism between transmitter and receiver, there are no relays used in the operation at either end of the line, only one instrument is employed, and the message is received ready for distribution. On the same basis of computation used in the above systems the speed of operation of the author's printing telegraph is 650 words per minute over a 375-mile (603.5-km.) line.

PLAN OF OPERATION

The method employed is direct throughout and the transmitting and recording parts are capable of such adjustment that the speed of operation is limited only by the speed of the line. The mode of operation is as follows:

By means of a punch which is connected to a commercial typewriter a half-in. (1.27-cm.) strip of paper is punched with a series of groupings of holes distinctively spaced in five rows, each group representing a letter. The punched strip of paper is then sent through the transmitter so that the holes pass under five wire brushes. Batteries of either polarity are thereby connected between the earth and either one of a pair of conductors. Batteries of different potential can also be used, and in one case that is done, making five different transmitting impulses. Fig. 1 shows the wiring connections, a representative piece of transmitting tape, the printing elements and a section of the record.

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[5] "Der Schnelltelegraph von Pollak und Virag", *Elektrotechn. Zeitschr,* Oct. 11, 1900.

"Recent Improvements of the Pollak-Virag Writing Telegraph," *Electrician,* July 3, 1903. "Telegraphie Rapide Systeme Pollak et Virag," *Ecl. Electr.,* Jan. 5, 1907.

At the receiver there are five elements which are separately controlled, except that No. 3, which needs only the normal current, also operates when the strong current needed to operate No. 5 is received.

The printing is accomplished by subdividing the alphabet into four independent elements and a fifth which, whenever used, accompanies one of the others. These elements then make an autographic record, by means of a local battery, on a moving sensitized paper whenever they touch the surface. It is merely necessary to have them operated in the proper sequence and with the desired interval in order to obtain any letter or figure of the alphabet.

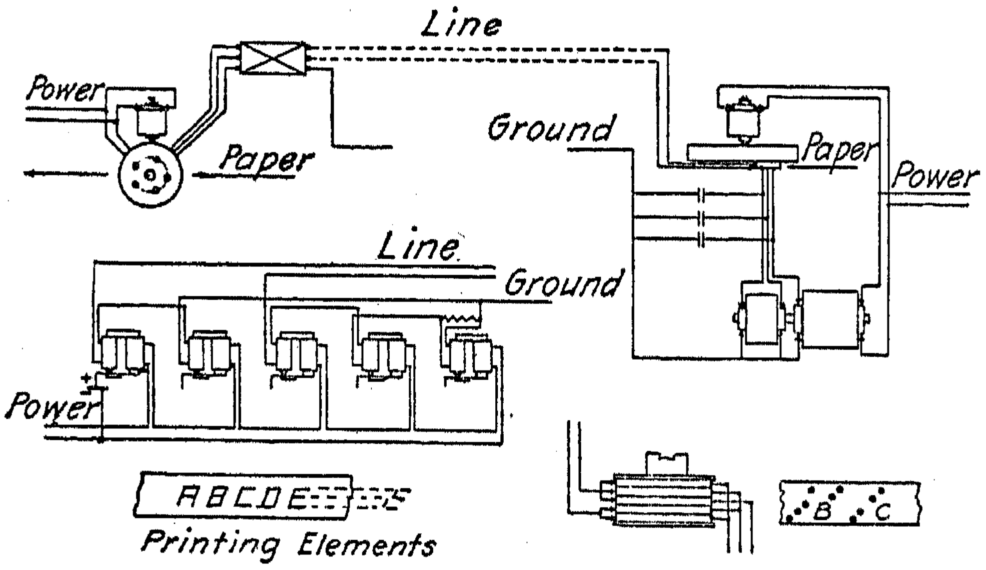

Fig. 1

Photographs of Complete Apparatus

Fig. 2 shows the punch for preparing the transmitting tape. A commercial typewriter is set on the punch base and the operation of preparing an office copy of the message also punches the transmitting tape. The depression of the digit bar sets the proper punch combination, then closes the circuit of an electromagnet which completes the operation of punching and spacing the transmitting tape. The tape is then rolled up ready for use on the transmitter. As many punching machines can be used at the same time as may be needed to supply the transmitter with a sufficient number of rolls of prepared messages.

Fig. 3 illustrates the automatic transmitter. The roll of paper carrying the message is driven under the wire brushes, which drop through the holes and make contact with the underlying rings, five in number. These rings are slowly rotating, driven by the paper friction, so as to insure a continually changing point of contact. No trouble at all has been experienced with faulty contacts. No speed control has yet been used on the driving motor as it has not been found necessary to have any exact speed of transmission.

Fig. 4 shows the method of construction of the artificial line, which needs more than a passing notice. It is made of a great many sections all connected in series. Each section consists of two tinfoil grids, separated by wax paper with solid tinfoil sheets outside of them, also separated from the grids with waxed paper. The solid sheets are 6½ in. by 9 in. (16.5 cm. by 22.8 cm.) and completely cover the grids, which are superimposed. There is thus complete distribution of the capacity and resistance of the two parts of the circuit with respect to each other as well as with respect to the ground, while each section is shielded from the neighboring sections. The total capacity from either line to ground, measured with an a-c. pure sine wave of 120 periods per sec., is 4.05 microfarads. The total resistance of each line is 747 ohms, while the leakage resistance due to dielectric absorption is 2×10^4 ohms. There is no appreciable self-induction. On the basis of an open wire circuit having a conductor 0.43 cm. in diameter, the capacity and resistance relation would make the artificial line equivalent to a circuit 375 miles (603.5 km.) long.[6] Since the open wire line has also distributed self-induction, the current at the distant end of the actual line would be greater than that at the end of the artificial line, if the impressed e.m.f. were the same. The equivalent length of actual line might be calculated in another way on the basis of an alternating current of equivalent frequency. When transmitting messages at the rate of 650 words per min.

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[6] NOTE—The above equivalence is obtained by interpolation in the table on p. 256 of "The Propagation of Electric Currents," J. A. Fleming.

the actual duration of an impulse is 1/720 sec. This would be equivalent to a frequency of 360 periods per sec.

$$\text{Assume } I_r = \frac{V_s}{Z_0} \operatorname{cosech} P l \qquad (1)$$

$$\text{Where } Z_0 = \text{initial sending end impedance} = \frac{\sqrt{r + j x}}{\sqrt{g + j b}} \qquad (2)$$

$$\text{and } P = \text{propagation constant} =$$

$$\alpha + j \beta = \sqrt{r + j x} \sqrt{g + j b} \qquad (3)$$

r, x, g and b are respectively the resistance, reactance, conductance and susceptance per mile.

I_r and V_s are the current at receiving end and impressed e.m.f. at sending end.[7] With the same V_s the I_r will be the same in an artificial line and actual open wire line if the length of the line, l, is 635 miles (1021 km.).

If the actual open line, however, is of No. 8 B. & S. gage, then with the same impressed e.m.f. the current at the end of 375 miles will be the same as at the end of the artificial line. The length of the open line equivalent to the artificial line can be conservatively placed at 375 miles. The oscillograph record shown in Fig. 7 gives the current distortion, due to the long line, which is found in this case.

Fig.5 shows the receiver of the author's printing telegraph system and Fig. 6 is another view of it with the head lifted from the tape to display the printing elements. It uses two local circuits; one energizes the magnetic circuit which normally holds the printing members off of the recording surface and polarizes them. The other is in series with a resistance and has its positive terminal connected to the receiver elements, which are here also the printing members, while the negative terminal is connected to the slightly moistened tape. A ferrocyanide of potassium solution, and iron tips to the receiver elements, have been found to be cheap and satisfactory. The line circuits are connected to the receiving spools and temporarily change the magnetic flux as

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[7] Note—See page 84, Fleming, *loc. cit.*

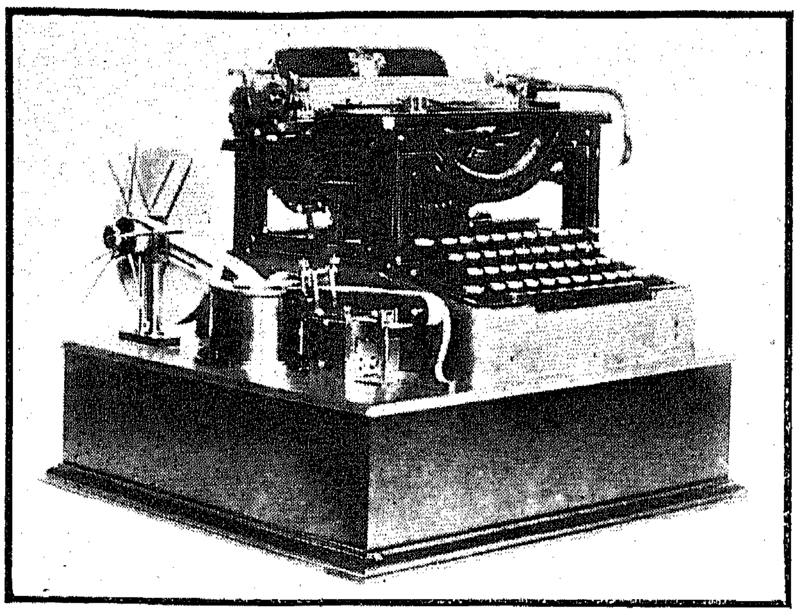

FIG. 2 [KINSLEY]

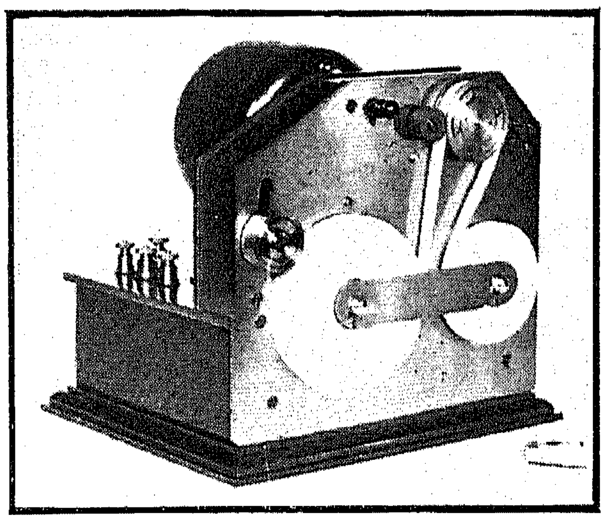

FIG. 3 [KINSLEY]

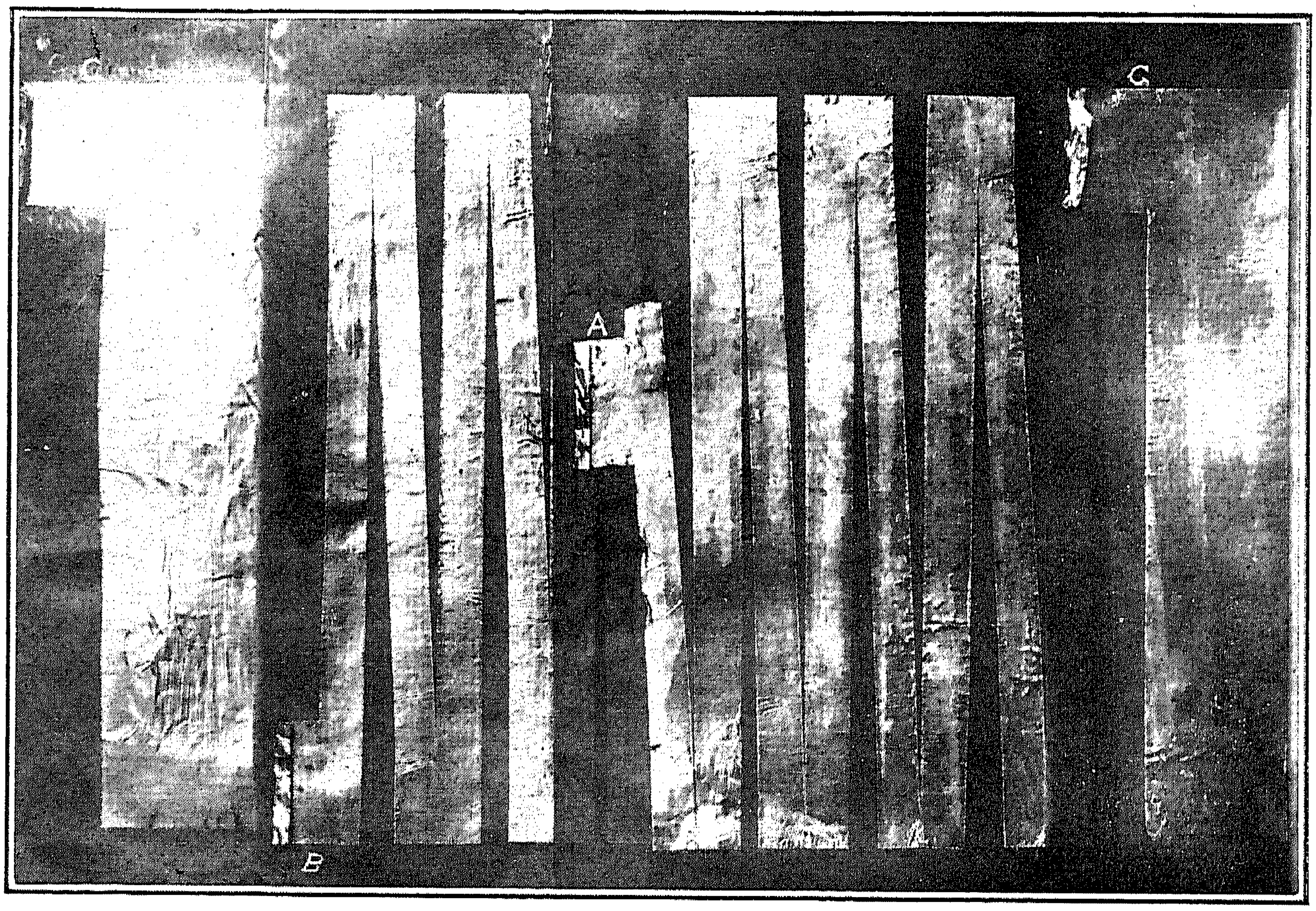

FIG. 4 [KINSLEY]

PLATE LXXVI,
A. I. E. E.
VOL. XXXIII, 1914

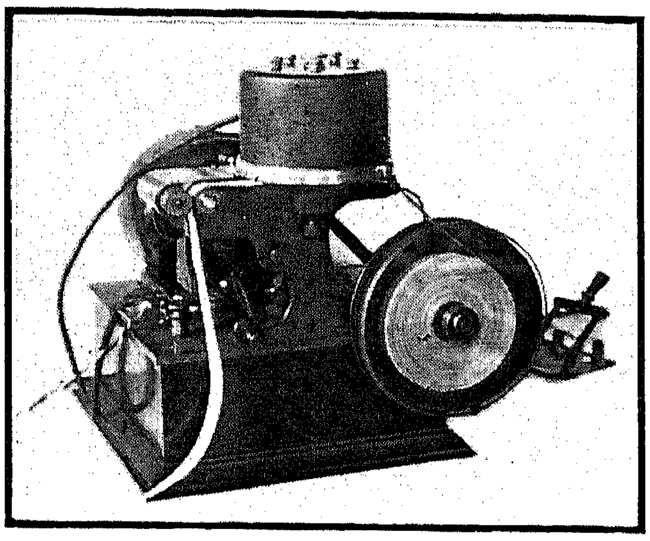

FIG. 5 [KINSLEY]

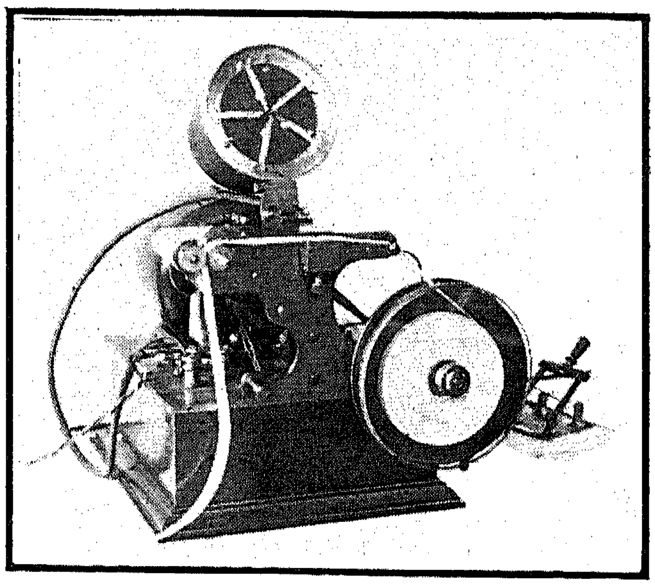

FIG. 6 [KINSLEY]

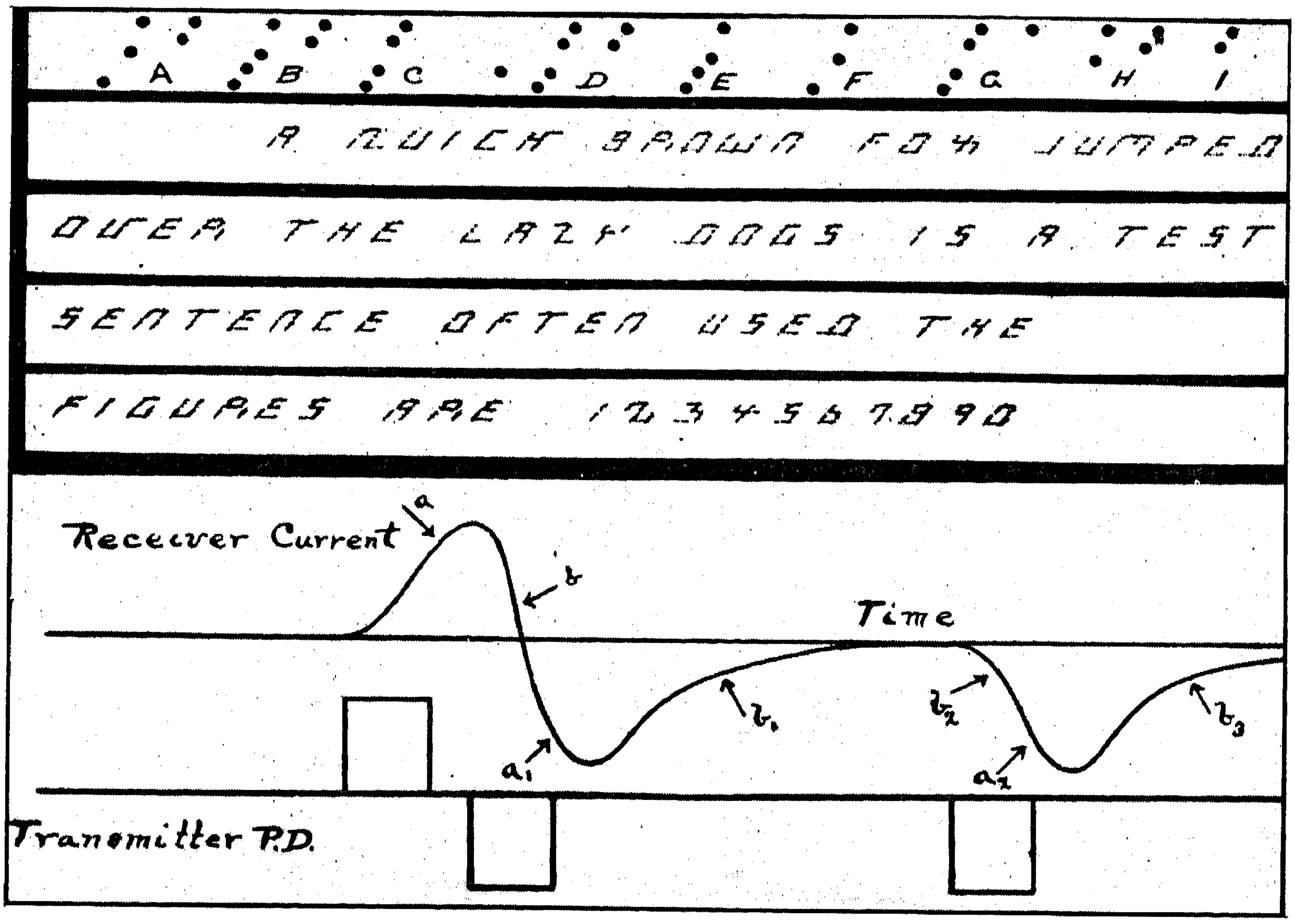

FIG. 7 [KINSLEY]

the signaling currents are received. It is found to be desirable to use various magnetic fluxes in the different circuits but in every case the magnetic density is not large when the parts of the magnetic circuit are proportioned as in this receiver.

The five elements are mounted on a circular frame so that the printing faces nestle closely together and form the pattern already shown in Fig. 1. This pattern is only one of several which have been tested. The form of the alphabet produced by it seems to be entirely satisfactory. A sixth element could be added if greater perfection were desired, while an alphabet of four elements which was thoroughly tried out was found to be legible to most people, but vastly inferior in appearance and doubtful of acceptance by the public. A sample of the transmitting tape and of the message as received is shown in Fig. 7, although the dark blue record on a slightly tinted background is a difficult object to reproduce photographically, and it is impossible to do justice to the original. The reproduction serves, however, to show the forms of all of the letters and figures as received over the whole of the artificial line, whose constants have been given, at a rate of 650 words per minute.

OPERATION OF THE RECEIVER ELEMENTS

The receiver is astonishingly consistent in its operation and it would probably be of interest to consider its functioning more in detail. The adjustment of the position of the core of a receiving magnet is accurately made by means of a reducing gear, all lost motion being avoided by the use of a stiff spring. After adjustment the receiver can be operated for a long time without any further attention. In one case, over four months elapsed without touching an adjustment screw, during which time it gave perfect service, then a break in the circuit made a repair and readjustment necessary. When a signaling current is received it will further magnetize the receiving magnet of one section of the receiver and reduce the magnetization of the one connected in series with it. The magnetization due to the local current lifts the receiver element from the paper and holds it against the core of the receiver magnet. When the signaling current slightly reduces the pull on the receiver element it is released, and the spring causes it to strike the paper, leaving its record, and then to rebound, when it is again caught by the local magnetic curcuit and held, ready for another release by the signaling current. The local current therefore does the work of distorting the spring and the signaling current merely supplies enough energy to release it and to allow the stored-up energy in the spring to become effective. The receiving element has a flat spring rigidly attached to the core of the magnet which is energized by the local current. The natural period of the printing element can be made whatever is desired by varying the thickness or width of the spring and the size or location of the attached armature. The natural period of the receiving element should lie between rather sharply defined limits. Its period should be sufficiently long so that the signaling current has passed and the magnetizing current is again the controlling quantity before it returns to its resting position; and the period should be short enough so that the receiving element is back at rest before another signaling current intended to operate it is received.

Let us assume that the transmitter connects batteries directly between a line and the ground either with or without the condensers which are of service only when the source has large self-induction. Fig. 7 shows the current at the end of a 375-mile artificial line, due to the impressed constant e.m.f., as obtained by photographing oscillograph curves at both transmitter and receiver. The current is such as would be used in the vertical lines of a *G*. If we consider the negative current, which releases the element making the lower half of the vertical line for its two strokes, it can be seen that the natural period of the element should lie between definite limits. Since the element is more strongly held in place while the positive current impulse is on the line but is released when the negative current reaches a_1 and held again when the current is not more than b_1, then the period of the printing element should be longer than the time between a_1 and b_1 but shorter than the time between a_1 and b_2. There is one exception that is of minor importance, since it is desirable to avoid synchronism in general, that is, if the natural period is exactly as long as the interval from a_1 to a_2 then the second release will come at the proper time. If the natural period has a value such that the element returns to its initial position at any time between b_2 and b_3, except at a_2, then the resulting stroke will be given at the wrong time. This may not be so far wrong as to lead to illegibility, but will obviously give an imperfect result. The natural period used with this instrument as now adjusted lies half way between a_1 and a_2. This high natural period allows the use of the " " marks which are not considered a necessary part of the telegraph alphabet.

Hundreds of oscillograph records have been made, and it can be stated positively that with the present circuit and apparatus design no combination of currents can occur which will cause errors in the record. It is evident that a sufficient increase of speed or an increase in the length of the line without an appropriate reduction of speed will produce an inoperative condition, but as previously stated, the speed attainable is limited by the line and not by the terminal instruments.

The elements most frequently used are the two which combined make a straight upright line. This is produced, as already shown in Fig. 7, by connecting the battery to the line for 1/720 of a second and then reversing it for the same interval. This can be considered as a part of a periodic wave having the equation[8]

$$V_s = \frac{4\,E}{\pi} \sum_{0}^{\infty} \frac{1}{2\,m + 1} \sin \frac{2\,m + 1}{T}\, 2\,\pi\, t \tag{4}$$

V_s = potential difference at transmitter at the time t counted from the time the positive potential is connected to the line.

E = potential difference of battery.

If we assume that the actual transmission will be equivalent to the sum of the series as far as the terms are appreciable, using $m = 0, 1, 2, 3$, etc., it will be possible to combine the arriving waves and obtain the arrival curve from the equation computed separately for each period, *i.e.*, for each value of m.

$$I_r = \frac{V_s}{(Z_s + Z_r) \cosh\, Pl + \left(\frac{Z_s\, Z_r}{Z_0} + Z_0 \right) \sinh\, Pl} \tag{5}$$

Z_s, Z_r and Z_0 are the impedances of the sending and receiving apparatus and the initial sending end impedance.

$$\begin{aligned} Pl &= \alpha\, l + j\, \beta\, l = l\, \sqrt{r + j\, x}\, \sqrt{g + j\, b} \\ &= 2.62\ \underline{/44^\circ\ 26'} \text{ for } m = 0 \end{aligned} \tag{6}$$

---

[8] The form employed is that used by Malcolm, *Electrician*, April 15, 1912, p. 916; eq. 32.

$$Z_0 = \frac{\sqrt{r + jx}}{\sqrt{g + jb}} = 285.5\ \overline{\backslash 45^\circ} \text{ for } m = 0 \tag{7}$$

$Z_s = 0$ when batteries are used.

$$Z_r = 56 + j\,859 = 862\ \underline{/86^\circ}\ 15' \text{ for } m = 0 \tag{8}$$

$$\text{For the first harmonic, } m = 0,\ I_r = \frac{V_s}{2320\ \underline{\backslash 174^\circ\ 7'}} \tag{9}$$

The 2d harmonic, $m = 1$, has an amplitude of only $2\frac{6}{10}$ per cent of the first, and 3d harmonic, $m = 2$, has an amplitude of only $\frac{35}{100}$ per cent of the first.

In other cases with shorter lines the harmonics up to the fifth may be appreciable, but they in no way interfere with the operation of the receiver if the receiving elements are properly designed.

At the receiver, the current flow, so far as it materially affects the printing elements, is therefore a sine wave of frequency 360 periods per sec., as is apparent from an inspection of the oscillograph curves of Fig. 7.

No estimate will be made of the cost per message, but the various items which have rendered other printing telegraphs too cumbersome or expensive for general commercial use are here conspicuously absent. The whole receiving and printing part of the mechanism can be easily held in the hand or carried in one's pocket. Aside from the paper drive and the power circuits there are only five moving parts and they consist of stiff flat springs rigidly attached to the frame. The movement of each is less than 1/25 of an inch (one mm.) and there is no possibility of their getting out of order or needing adjustment. If the paper drive is started by a line impulse from the transmitter, a message could be received without the necessity of an attendant ever being present. The receiver, due to its extreme simplicity and entire absence of delicate parts, would have its first cost considerably less than that of a single sensitive relay. The cost of maintenance and operation will obviously be reduced to a minimum, since on account of its simplicity and speed the number of attendants and their individual skill will be far less than at present needed. Of the entire system, the most complex part as well as the most expensive is the commercial typewriter. It is not altered in any way, and if large users of the telegraph should themselves prepare the transmitting rolls the typewriters would be available at other times for general office purposes.

The widespread interest in and need for a cheaper telegraph service should undoubtedly lead to the adoption of some machine method of telegraphy which would make possible a large reduction in telegraph tolls.

DISCUSSION ON "A HIGH-SPEED PRINTING TELEGRAPH SYSTEM" (KINSLEY), DETROIT, MICH., JUNE 26, 1914.

C. R. Underhill: Mr. Kinsley is certainly to be congratulated on the very ingenious device which he has brought out, and I must say that it is one of the most surprising forms of high-speed printing telegraph instruments which have come to my notice. It seems, however, that it is necessary to use two wires and ground, which makes the line expensive, particularly since the machine is designed, I presume, for long-distance transmission, as that would be the service in which it would apparently have its greatest value, but the use of two wires may not be so detrimental as at first appears. Probably one great reason why the printing telegraph has not been adopted more in this country as compared with European countries is because in foreign countries the telegraph is used for letter-writing. Abroad, I understand that it is customary to send a telegram instead of a letter, and for that reason the traffic is increased and the price is brought down.

Some years ago, in 1904, I brought out a printing telegraph which has never been made public except through the patent offices of the world, and which has been kept quiescent for certain reasons which need not be mentioned. My object in bringing out this telegraph instrument was based on the fact that the Morse system is in universal use not only in this country, but abroad, not only for short distances, but for great distances, both for wire and wireless telegraphy, and might be called the universal telegraph system. This instrument to which I refer was so designed that it would print in English characters on a tape, something like a stock "ticker", that is, it would translate from the dots and dashes of the Morse code into type. I had a great deal of difficulty on account of certain letters in the Morse code, *i. e.*, C, O, R, Y, Z. I had no difficulty in making it work on the Continental or Universal code.

There is a point I wish to bring up in connection with the introduction of a machine of this character. The telegraph companies of the United States and Canada are very slow in adopting the Continental or Universal code, although it is used abroad, and in the wireless field. It is not unusual for operators to receive messages in the Continental code and send them out again in the Morse code. On the long trans-continental lines they do use the Continental code, to a certain extent. It has been shown that operators in the wireless field readily learn the Continental code, although accustomed to the Morse code, yet the telegraph companies will not adopt it. There seems to be some inertia there.

I would like to ask what effect the line leakages due to weather have on this instrument. Although Mr. Kinsley stated there is no local battery, I understand a local battery has to be used for holding up the armature, as he explained. I would like to know whether a careful balance has to be maintained in the magnets. We know the quadruplex will not work well whenever there is considerable leakage on the line on account of the weather. I would like to know how line leakage affects these magnets, and whether adjustments have to be made, locally, when the line current varies.

My experience with the telegraph instrument I mentioned has, I think, an important bearing on the introduction of a machine of this kind. I took it before the high officials of one of the large telegraph companies. They received it very nicely and said it was a very ingenious device, etc., but they led me into the operating room and showed me a man sitting before a resonator, with a sounder in it, the man operating a typewriter and taking the matter down at the rate of about thirty-five words a minute. The official said, "You watch that operator." By chance the operator "broke," took the paper out of the typewriter, made a correction on it, put it back and started typewriting again at the rate of about one hundred words a minute. During this interval he was storing the message in his head. The official said, "You bring us a machine that will dispense with the operator, and we will put it in."

In connection with the matter of the two wires, I wish to add that one of the officials, in speaking of the capacity in connection with any machine, said, "Whenever further capacity is needed, we have plenty of wires running between New York and Chicago, and all we have to do is to tap in on another wire." It may be in a case like that, since they have so many wires, it makes no difference whether you use a single wire or three wires at a time. Incidentally, I might add that a code system like the Morse or Continental is applicable both to wire and wireless, whereas I know of no other system which can be applied to both. I have made my system work on the wireless.

Ralph W. Pope: I was particularly struck with the novelty and ingenuity of the system proposed by Mr. Kinsley. It takes me back to the time when there were objections raised to the printing systems then in use. I first learned to operate the Hughes printing telegraph in 1858, and learned the Morse as a side issue and for amusement. What was amusement then became business thereafter, for the printing instruments were gradually discarded. In the days of the printers, the first being the House, followed by the Hughes, we were very careful about sending out good copy, that was perfectly legible and could be read without difficulty by any one. The House machine was inferior in this respect, for the reason that instead of printing direct from the type it made an impression through a carbon tape onto the paper, and the fine lines of the letters were somewhat blurred and the copy looked smutty, but still it was very good if the tape was kept in good order. The Hughes printer, which followed, printed directly from steel engraved letters, the same as the ordinary type used in printing a news-paper, while the House was similar to the carbon tape on the typewriter. You see we have made considerable improvements, in that the result of a carbon tape today is better than that we used to get from the House printing tape years ago. Legibility, then, was one of the desirable things, but there was another important feature, important in a negative sense—business men did not like the tape, for the reason that it was not the proper kind of a document to file away, and when I was a private secretary and received these tape telegrams in the course of business, one of the jobs of the office boy was to tear the tape into pieces five or six inches long and paste them on a sheet, so that we could file them away. In those days, as I recall, no effort was made towards producing the "page printer," but today we have page printers. The type wheel shifts along on the shaft, and when it comes to the end of a line it goes back. I am not familiar enough with the experiments of Mr. Kinsley to know whether he has undertaken anything of that kind.

We come then, to this question of legibility, and I notice in the paper the author says that the letters and figures can be made more perfect by the use of a sixth element. In the samples presented by Mr. Kinsley it does not seem to me that the figures, more especially, are sufficiently distinct. Figures in a telegram are quite important; I do not refer so much to figures in the body of the message, making errors in reading quotations, for instance, but in the addresses on messages; and the number on the street is not so important as the number of the street itself. Because, if you have a telegram addressed to the right street you are quite likely to find the right number. I have noticed the figures 168, as they appear on this slip. In Washington, that might be read, possibly, 16 B street, or in New York it might be read, instead of 168th street, 108th street, not by an expert, but by the boy who addresses the envelope. So that it appears to me that the figures should be so perfect that there is no possibility of there being errors made in reading them. That is, as you will see, more important than the matter of letters.

For more than forty years, experimenting has been going on with systems of rapid telegraphy. That has always meant the preparation of the message in advance by perforating paper, and running it through rapidly, in order to get this high speed of 650 words a minute. That means that the sending matter must be divided up amongst a few "punchers," as they are called, whereas with the Kinsley instrument, when the message is ready for delivery, it has gone through no other process at the receiving end, and the tape is supposed to be ready to deliver. That has not been the case heretofore with these received messages, they had to be divided up and recopied, on the same principle that they were divided up for punching. While it is desirable, perhaps, to get this high rate of speed, there is another question to be considered, which was brought to my attention

Sir William Preece at our meeting in April, 1907, when we cussed the Rowland printing telegraph. Sir William said ıt one of the difficulties they had with these fast systems in gland was to get business enough to work the system up to capacity. There were only a few through trunk lines between ndon and Liverpool, and London and Glasgow, perhaps, where ·y could work these fast systems economically, for the reason ·y would run out of business and would have to wait for more. consider that telegraphy, when you recognize its value, is of the cheapest things we have, but the average individual ely sends a telegram on his private account. It is only the at business houses, especially brokerage houses in the ge cities, which spend such large amounts in telegraphing. ave gone sometimes from one year's end to the other without ding a private telegram, but that is more especially the case e we have had the telephone. So that the cost of telephing is a very small item in the expenses of the average ısumer.

ears ago I wrote an editorial on this subject, and took for text the cost per ton of making stoves in Troy. I happened run across this list of items that went to make up the cost ı ton of stoves—so much for iron, so much for labor, and so running up, as I recall it, to about $80 a ton, while for post- and telegraphing, which were lumped together, it was $1 he cost of a ton of stoves, and bad debts were placed at $2, hat really this amount of bad debts was double the cost of grams and letters.

have always maintained that telegraphing should not be apened. This also was an argument put forward by Mr. ıin, who was one of the officers of the first telegraph comy in the country, I think, at Philadelphia, when he said y were making a mistake in trying to cheapen the work of telegraph.

efore typewriters were used it was considered necessary every operator should write a clear hand, not necessarily dsome, but plain. It is now obligatory, in most offices, to a typewriter for transcribing messages instead of longhand. we have seen an evolution, even in the simple Morse, first n the use of a metal type notched, for transmitting purposes, up in a stick and run along, because the inventor thought operator could not make the signals plainly enough. Then vent to the key sending and received messages on the tape. n the embossing register was discarded, when the operators overed they could read the signals by sound and do it much e quickly, and more accurately, and keep up with the ler. That is one thing you lose in any system of the kind er discussion, you lose that time which is required in punchthe tape. In receiving by sound, ordinarily the operator ose up with the sounder; to be sure, as the previous speaker said, they may lag behind for a dozen words, and catch up —that is one of the peculiar features of Morse telegraphing, the ability of the operators to carry along, some of them twelve or twenty-five words, perhaps, behind the sounder and keep these words in memory, while they are turning their carbon sheets, or putting in fresh carbon sheets, and the various other details which are necessary. That is what I used to do when I had to wait on myself and was fixing up carbon sheets for three copies. While I was doing that, the sounder was going on, and when I began the next page I would be a dozen words behind and then would catch up, and be ready to change the next page.

I was speaking of the evolution of the Morse simply by the practical experience and growing skill of the operators. I might say there was always a rivalry between the sending operator and the receiving operator, as to which could work the faster, whether the sending operator could send faster than the receiving operator could receive it, and it was about neck and neck until the typewriter operator arrived. When the typewriter came, the receiving operator had it all his own way, he could almost take a nap in between times, because he could take ten or fifteen words more per minute more than the sending operator could send.

What has happened now? The telegraph company has eliminated all of the conventional signals, formerly required in sending messages. They used to put "ahr" for "another," and "fm" for "from" on our messages. Now, the company, to save time, has eliminated these things, and the receiving operator must be still more expert, because he has no breathing spell. As the operators found they could receive much faster with the typewriter, the company said, "If you can receive so much better by typewriter, you must all do it." So they all do it. The typewriter is in practically universal use today.

We have seen that the receiving operator has more leeway with the use of the typewriter, but in press reports the Phillips code is used by the sender. The Phillips code is an authorized system of abbreviation. This does not apply to the ordinary messages, which are not allowed to be abbreviated. I will give this instance of one word—"scotus." This means the Supreme Court of the United States. When a man receives the word "scotus" over the wire, on his typewriter he must write out the words "the Supreme Court of the United States." That is rather an extreme instance, but it is an example—"scotus" is made up of the initials of the words. The code is copyrighted by Walter P. Phillips, the inventor, and is published in book form.

A word about the present Morse alphabet. It is a very simple matter for an operator to send or receive by either code if he is familiar with them, just as it is easy for Mr. Mailloux, for instance, to state a proposition in nine different languages, so that it is simply a question first, of the Morse operator learning the Continental code, as it is called, which is a very simple matter. It is now required in the wireless service. It would probably only be necessary for the telegraph companies to say that after a certain date, the first of October, for instance, the Universal alphabet shall be used instead of the Morse. But the question of superiority is not quite settled. When the old Bain chemical telegraph, which was a rival of the Morse, was in operation, the Bain alphabet was used, which by many was considered superior to the Morse, and there were many operators, especially in New England, who knew both alphabets. The Bain code is now obsolete.

There is one more question I want to ask of the author. Fig. 7 shows that the dots used for "C" and the dots used for "G" are practically the same, in the case of "G" there being one added, and the same combination of double dots appears in the case of "D." I was a little at a loss to know how the combination came in "I," because the curve is reversed, and I am not certain whether it is possible to reverse the curve or not.

George S. Macomber: I think we should congratulate Mr. Kinsley on his very happy and novel combination of inventions. It seems to me that almost all inventions of this kind are really new combinations of things known before. In the present case we have a type printer operated by electromagnets, combined with an electrochemical telegraph recorder.

All high-speed telegraph recorders may be divided into two general classes, electromagnetic and electrochemical. We have three sub-classes of electromagnetic recorders: (a) those operated by non-timed step-by-step mechanism, as in the case of the various "tickers"; (b) those operated by synchronous motors, as in the case of the Hughes, the Phelps, the Baudot, and the Rowland printers, and (c) those operated by non-synchronous timed impulses, as in the case of the Morkrum printer, in which six electromagnets are successively and automatically operated at definite time intervals after the first or starting impulse is received, and in which the various letter combinations are determined by the arrival or absence of positive or negative current impulses at the receiver as each of the timed magnets respectively operates. We have two sub-classes of electrochemical telegraph recorders: (a) those using unidirectional current, as in the early Bain two-wire telegraph; and (b) those using both positive and negative line current impulses, as in the Foote and Randall and the Delany telegraphs.

Mr. Kinsley's telegraph uses a perforated tape with five rows of perforations somewhat like that of the Pollak-Virag telegraph tape; a transmitter which sends both positive and negative current impulses over the line as did that of Foote and Randall; a two-wire transmission line as did the first Bain system; and a chemically prepared tape, similar to that used by Bain and Delany, in a recorder so arranged as to make, electrochemically, successive lines so placed on the tape as to form or at least imitate type print.

I want to ask Mr. Kinsley how many unit time intervals are required, on the average, by his recorder, per letter. It appears from Fig. 7 that some letters, as, for example, "B," must require more time than other letters, such as "I".

I wish also to record a correction of the generally accepted notion that Alexander Bain was the first to produce a chemical telegraph recorder, for as early as 1828, Harrison W. Dyer built an electrochemical telegraph recorder and operated it over a line several miles long.

Carl Kinsley: In answering the first question, in regard to leakage and difficulty of balancing, since there is no battery at the receiving end which takes part in the operation of the line current, the battery at the receiving end merely magnetizes the local circuit. In the sending end, is the only battery which takes part in the operation of the line. In instruments with a neutral relay, such as the Edison quadruplex, half a dozen different operations have to be gone through with in order to receive one signal, to quote from "American Telegraphy," by William Maver, Jr., (New York, 1903; page 198):—"it is quite demonstrable that during the making of a dash on the neutral relay at one station the distant pole-changer may reverse its battery several times; the home pole-changer may do likewise and the home transmitter may increase and decrease the electromotive force of the home battery, repeatedly. At the same time, and, of course, as a result of the foregoing actions, the home neutral relay may have had its magnetism reversed several times, and the signal will have been made, partly by the home battery, partly by the distant and home batteries combined: partly with current on the main line, partly without: partly by the main line 'static' current, and partly by the condenser current, and yet on a well-adjusted circuit it will have been heard on the quadruplex sounder as clearly as any dash on an ordinary 'city line' sounder."

There is nothing of that kind in connection with this instrument. There is merely a positive and negative to line from the transmitter, and it works one particular element, or in one case two elements, and tends to hold up the other one on the line, because these elements are in series with each other; consequently there is no difficulty—any line that is good enough to operate a polarized relay will operate this with current less than is necessary with the usual polarized relay, because the operating energy does not go over the line; the operating energy is supplied largely by the local circuit, and what goes over the line is merely enough to upset the balance between the local magnetic circuit and the tension on the spring.

C. R. Underhill: In case of leakage, could you get enough current to operate satisfactorily?

Carl Kinsley: You can get all that you can from any telegraph line for operating any relay. There is a point where all telegraph lines break down.

C. R. Underhill: Does that come from that kind of balance—in case you had plenty of current, or very little current, would it have to be adjusted to balance?

Carl Kinsley: There is no balancing on the line in that sense. You merely have to arrange the instrument so that it will always operate when the current reaches a minimum value, and it will operate for any value above that. There is no margin of working in that sense.

In regard to the use of six elements, I like the five better, as being more simple to operate. The sixth element will give, possibly, some increase in the beauty of the alphabet, because there can be made certain distinctions with six which cannot be made with five, but, in my opinion, the alphabet made with five elements is perfectly legible. However, if for any reason the five-element method is not sufficiently graceful, then it is possible to use the sixth. As a matter of fact, four elements have been used, and give a legible alphabet to readers familiar with its use but it lacks the characteristic of being familiar to all.

In regard to Fig. 7, it was suggested that "C" differs from "G" in that there is a second use of the lower half of the vertical line in "G". How that differs from "O" is that there is no second use of the upper half of the vertical line. In the "G" the currents are first positive and then negative over one line, second positive and then negative over the other line, the negative following immediately after positive, and then a wait, and then another negative over the second line. Sometimes there are two impulses in the same direction following each other, but they are followed in the next vertical line by positive and negative. There is no building up of charge in the line, and it has been found that the line can handle two, where it cannot handle five successive impulses in the same direction. This system keeps the line clear for each succeeding letter, starting as it does with positive and negative, which has the effect of clearing the line.

There was another question, I think by the following speaker, asking how many impulses were taken per letter—he said how many "time impulses;" I think he meant how many impulses per letter. That varies with the letter. The time element enters into this system—a certain time must be allowed for the receiving tape to get away before printing the succeeding letter. It does not make any difference how many impulses are sent in making a certain letter. The time allowed for a single letter is sufficient for twelve time impulses. As a matter of fact the number of current impulses in that time may only be three or four, but sufficient time must be allowed for the paper to clear. It does not increase the speed to have fewer current impulses, since it is necessary to allow a certain time interval to elapse to give room for the next letter. Twelve time intervals will give sufficient space, and inside of that time there can be as many current impulses as you please, since the positive and negative follow each other and keep the line clear.

Presented at the 31st Annual Convention of the American Institute of Electrical Engineers, Detroit, Mich., June 26, 1914, under the auspices of the Telegraphy and Telephony Committee.

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TOLL TELEPHONE TRAFFIC

An Experimental Study of the Relationship between Circuit Loads and Delay to Traffic

BY FRANK F. FOWLE

Abstract of Paper

Experiments are described to determine the relationship between telephone circuit loads and the corresponding delay to traffic. The operating methods employed and the number of circuits available determine in general the number of messages per day which can be handled over a single toll circuit. The average delay to traffic obviously depends upon the number of messages per circuit per day, or the circuit loads. With a given load factor, increase in the circuit loads will increase the average delay to traffic. At the same time the revenue per circuit mile will correspondingly increase. The practical limit, however, is approached when the delays to traffic reach a point where the service is unsatisfactory. The results of the experiments described illustrate the fact that increasing circuit loads increase the delay to traffic, and vice versa. The revenue per circuit mile is directly proportional to the product of the circuit load and the toll rate per minute-mile; consequently the relationship between the quality of service and the toll rate is generally obvious, assuming a certain rate of return on the plant investment.

THE NUMBER of telephone messages per day which can be handled over a single toll circuit, as is well known, depends upon several considerations. Chief among these are the operating method employed and the number of circuits required to handle the total traffic between the given terminals. A complete dissertation upon toll operating methods would extend far beyond the scope of the present paper, and only the simplest or fundamental methods will be mentioned. The earliest method, and one still used to a great extent in handling small volumes of traffic, is the direct ring-down, in-and-out ticket (or two-ticket) method. In this method the operators signal each other direct, over the talking or message circuit, by ringing in the usual manner; the outward operator makes a complete ticket, and times and supervises the connection; the inward operator also makes a duplicate ticket, but does not time the connection. This method has been materially improved by eliminating the inward ticket, and by having the outward operator deal directly with the called party at the destination instead of through the intermediary of an inward operator who repeats the details back to the outward operator. In some cases the last method has been modified to the extent of having the inward operator make a memorandum ticket or so-called skeleton ticket, for checking purposes, but this is usually eliminated if possible. Other operating methods, special in their nature, apply when the volume of traffic is very large, but do not come within the scope of the present discussion.

It is not necessary to dwell at length upon the fact that the number of messages per day, per circuit, increases (other factors being the same) as the volume of traffic and the number of circuits operated in one group to handle it also increase. That is, the circuit efficiency increases as the number of circuits or trunks in a group increases, and more messages per circuit, per day, can be handled in a large group than a small one, with the same average delay to traffic and equal load factors.

The effects of the operating method and the size of the trunk group upon the circuit loads (messages per circuit per day) are usually discussed from the standpoint of a certain fixed quality of service, that is, a certain average delay to traffic which is maintained as a standard. This period of delay is generally accepted as the interval from the time the calling subscriber gives his call to the recording operator, until the line operator establishes the connection or returns a definite report in regard to the called party. It seems fairly obvious, however, that there must be some definite relation between the circuit loads and the average delay to traffic. In other words, with a constant load factor, the effect of increasing the circuit loads will be to increase the average delay to traffic; at the same time the toll revenue per circuit-mile will correspondingly increase. Naturally a limit will be approached when the traffic is delayed to such an extent that subscribers complain of the delay and a loss of business is threatened.

This relationship between circuit loads (traffic density per circuit) and average delay to traffic, if not already clear, can be illustrated by a simple analogy with railway transportation. Given a fixed volume of traffic (passenger or freight) to be transported, the delays in traffic movement will be least when the train service is as frequent as it is possible to arrange it; but unless the volume of traffic is very large, the train loads may not be large enough to produce an adequate net revenue per train-mile. In order to increase the train loads to a point where the operating revenue per train-mile will exceed the cost by a reasonably profitable margin, it will perhaps be necessary to resort to less frequent train service. This implies a longer average interval between trains, and consequently a longer average period of waiting or delay before the traffic is moved. The parallels in the analogy are between the number of trains and the number of toll circuits, between train loads and circuit loads, and between delays to railway traffic and to toll traffic, a fixed volume of traffic in each case being assumed.

The general problem is therefore one of the highest commercial importance, since it is perfectly obvious that under a given schedule of toll rates there is a certain standard of service which cannot be exceeded without the sacrifice of profits, and the faster the service as a whole the higher must be the rates for the same percentage of profit. It is not at all the intent in this paper to reach any conclusions as to the commercial side of the question, but simply to present certain experimental data bearing on the general principle.

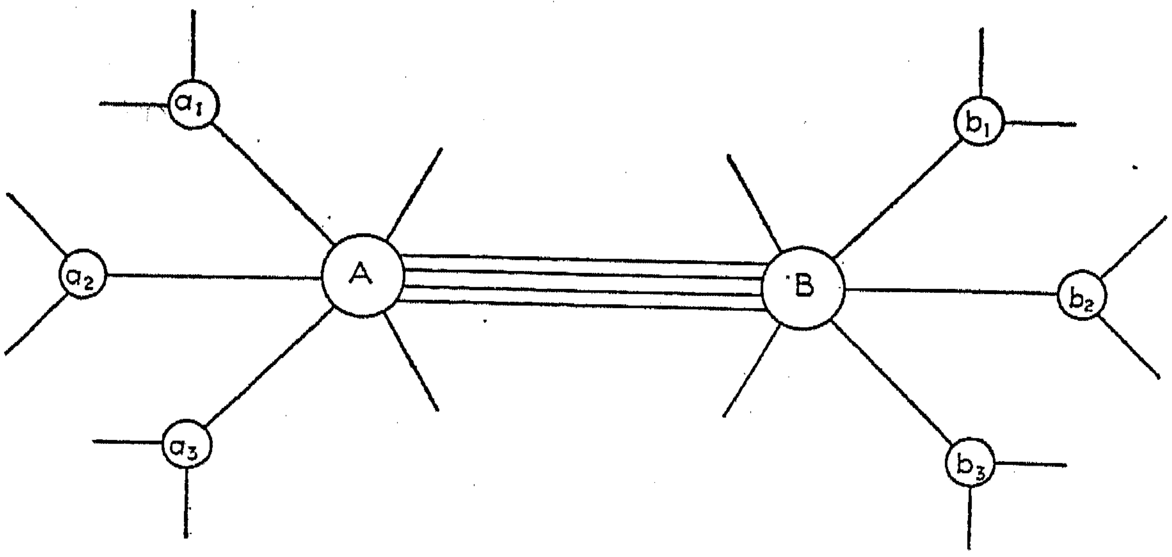

FIG. 1—PORTION OF A TOLL SYSTEM—TOLL CENTERS AT A AND B

LAYOUT OF EXPERIMENTAL CIRCUITS

The general layout of the toll lines used in the experiments here described is shown in Fig. 1. The group of circuits upon which the experiments were made extended between A and B, the latter representing two toll offices, or toll centers. The greater portion of the traffic either originated at A and terminated at B or vice versa. The remainder of the traffic was of a through (instead of terminal) character, necessitating the use of tandem circuits. For example, a call originating at A and destined for b_2 or some point beyond, would have to be switched at B; in some cases the call would be passed to the operator at B, who would take the details and record them on a through ticket, and then pass the call to b_2, while in other cases the operator at *B* would connect the line through to b_2 and the operator at *A* would pass the call to the operator at b_2. The entire traffic passing over the group of circuits between *A* and *B* can be classified as follows, for convenience.

TABLE I

CLASSIFICATION OF TRAFFIC OVER GROUP OF CIRCUITS BETWEEN *A* AND *B* IN FIG. 1.

A to *B* *B* to *A*	Class 1
A to b_1 or b_2 or b_3 *B* to a_1 or a_2 or a_3	Class 2
a_1 or a_2 or a_3 to *B* b_1 or b_2 or b_3 to *A*	Class 3
a_1 or a_2 or a_3 to b_1 or b_2 or b_3 b_1 or b_2 or b_3 to a_1 or a_2 or a_3	Class 4

Normally there were six circuits between *A* and *B*; this number was reduced successively to five and then to four, operating for several days under each of the last two conditions in order to secure reliable test data. A study of the traffic was then made from the tickets, excluding any days such as Sunday or Saturday when the traffic is not normal, and also excluding any days when there was any wire trouble on any of the circuits in the group. Of course it should be understood that the through traffic did not necessarily originate or terminate at the first office beyond *A* or *B*, but in some cases involved offices reached by two or more switches.

SUMMARIES OF TEST DATA

The operating method employed in handling the terminal business (class 1 traffic) between *A* and *B* (Fig. 1) was the direct ring-down, single-ticket method, while all other traffic was handled by the double-ticket method. The through business was handled in some instances by means of relays, or through tickets at the switching point, and in other cases by straight switches (no ticket).

The summary of results is presented in Table II. Recapitulating, the class 1 traffic is the terminal business between *A*

TABLE II

SUMMARY OF AVERAGE DAILY TRAFFIC OVER THE GROUP OF TOLL CIRCUITS BETWEEN A AND B (FIG. 1.)

Number of circuits in use	Class 1 traffic		Class 2 traffic		Class 3 traffic			Class 4 traffic			Total number of messages (2 switches taken as 1 message)	Number of messages per circuit	Revenue per circuit mile	Number of days' business averaged
					Relayed		Switched	Relayed		Switched				
	Number of messages	Average delay (min.)	Number of messages	Average delay (min.)	Number of messages	Average delay (min.)	Number of switches	Number of messages	Average delay (min.)	Number of switches				
6	124	7.0	19	17.	4	9.2	25	3	14.	2.	164	27.3	$.187	3
5	144	12.2	22	25.	8	5.8	41	3	20.	2.	198	39.6	.255	3
4	140	21.1	17	30.	13	21.	43	2	6.	1.	193	48.2	.314	2

and B (Fig. 1), the class 2 traffic is the through business originating at A and B, the class 3 traffic is the through business terminating at A and B, and the class 4 traffic is the through business to and from points beyond A and B but passing over the circuits between the latter. There was no simple way of determining whether each through switch at A and B was set up for the transmission of a message, but in general the number of switches exceeds the corresponding number of messages and it was arbitrarily assumed that there was one message for every two switches. The average duration of a message was approximately four minutes. The rate schedule in force was the same throughout each 24-hour period.

Table III shows a summary of lost and delayed business, for the same periods as represented in Table II. In all cases the traffic figures represent one day's business, being an average of several day's business, as indicated in the last column in Table II.

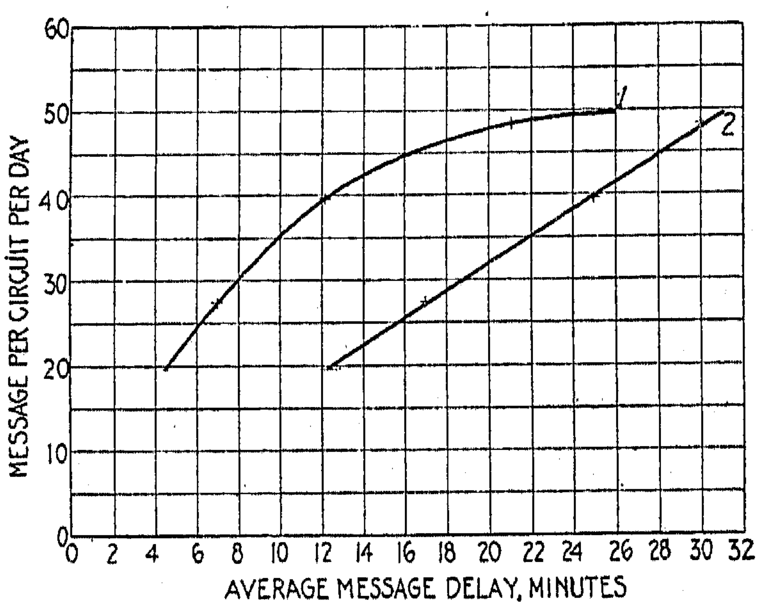

FIG. 2—CURVES SHOWING THE RELATIONSHIP BETWEEN CIRCUIT LOADS AND AVERAGE DELAY TO TRAFFIC
Curve (1) for terminal business.
Curve (2) for originating through business.

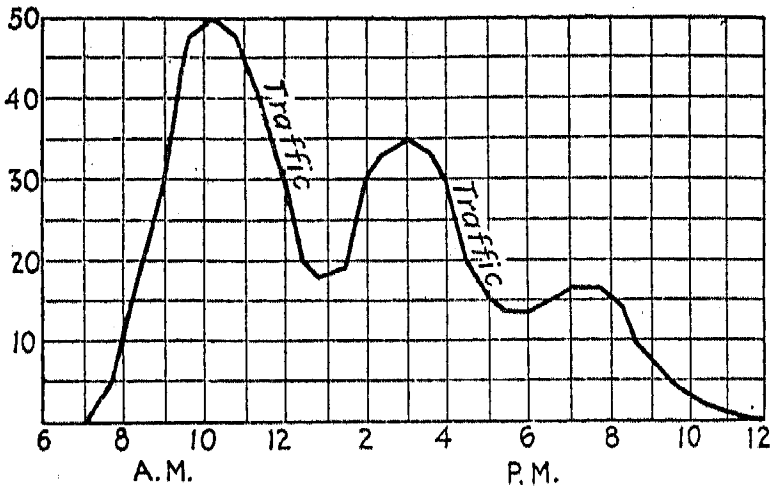

FIG. 3—TYPICAL LOAD CURVE OF TOLL TRAFFIC

DISCUSSION OF RESULTS

The relationship between the average delay to terminal business (class 1 traffic) and the circuit loads is plotted in curve (1), Fig. 2; the similar relationship for the originating through business (class 2 traffic) is plotted in curve (2), Fig. 2. The underlying data are taken from Table II. These curves bring out forcibly the general conclusion of the paper, namely, that increasing circuit loads are accompanied by increased average delay to traffic. For example, taking the terminal (class 1) traffic, five-minute service corresponds to a circuit load of 21 messages per circuit per day, in a group of about 8 circuits; six-minute service corresponds to a circuit load of 24 messages per circuit per day, in a group of about 7 circuits; seven-minute service corresponds to a load of about 27 messages, eight-minute service to 30 messages, ten-minute service to 35 messages, etc. The following Table IV was prepared in this manner from curve (1), Fig. 2; this of course is based primarily on handling a substantially constant volume of traffic.

TABLE III

SUMMARY OF LOST AND DELAYED BUSINESS.

Number of circuits in use	Per cent of originating calls (A and B) lost	Number of calls delayed by "no circuit" conditions	Average no-circuit delay, on delayed calls (min.)	Number of calls lost on account of "no circuit" conditions
6	18%	25	11.8	None
5	17%	62	12.9	1
4	21%	99	16.9	1

TABLE IV

CIRCUIT LOADS FOR VARIOUS GRADES OF SERVICE WITH CONSTANT VOLUME OF TRAFFIC AND A GROUP OF 4 TO 8 CIRCUITS

Average delay to terminal traffic (min).	Circuit loads in total messages per circuit per day
5	21
6	24
7	27
8	30
9	33
10	35
11	37
12	39
13	41
14	42
15	44

The volume of class 3 traffic, Table II, is so small that the data on average delay are unreliable. This is more obvious by reference to a typical load curve, Fig. 3. Evidently there is a large probability that these relatively few class 3 messages were handled during some other period than the peak, or the "busy hour;" and in such case the delay would be less, owing to lighter loads on the circuits. The same is true of class 4 traffic. The daily load factor was in the vicinity of 30 per cent.

The delay to originating through business (class 2 traffic), destined to scattered points to which the business did not justify individual direct circuits, is shown in curve (2), Fig. 2. Of course this delay can be minimized by eliminating relay tickets at switching points and substituting straight switches.

The use of averages, particularly in reference to the delays to traffic, does not convey complete information as to the character of service, since some of the calls will inevitably be delayed longer than the average, and others less. In order to bring out fully the quality or speed of toll service it is desirable to resort to curves of the type shown in Fig. 4. These curves show the percentage of calls handled with a given delay, or less, and therefore reveal the extremes. The three curves there shown give in more detail the grade of service obtained during the tests whose results are recorded in Table II. Each of these curves applies only to the terminal business, or class 1 traffic; the average delay in each case may be found in Table II.

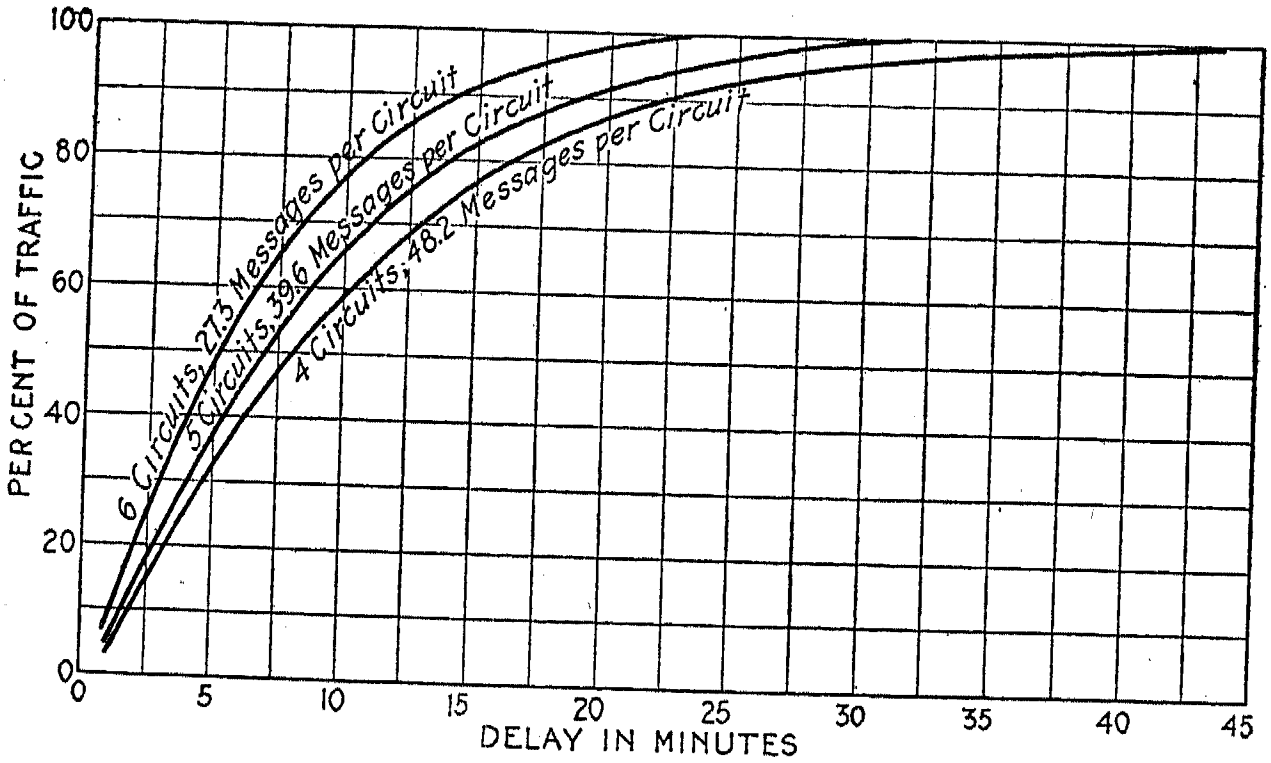

FIG. 4—PERCENTAGE OF TERMINAL TRAFFIC HANDLED WITHIN A GIVEN INTERVAL OR LESS

The results given in the paper, although they apply specifically to conditions which do not differ widely from those described, nevertheless serve to illustrate the fundamental principle that increasing circuit loads increase the delay to service, and vice versa. The revenue per circuit-mile per day, or per annum, is directly proportional to the product of the circuit load and the toll rate per minute-mile. Consequently the relationship between the quality of service and the toll rate schedule is in general an obvious one, assuming of course that a certain fixed percentage of return on the plant investment is maintained in all cases.

DISCUSSION ON "TOLL TELEPHONE TRAFFIC" (FOWLE), DETROIT, MICH., JUNE 26, 1914.

J. Lloyd Wayne, 3rd: I think this subject of telephone toll traffic is very close to the heart of every operating telephone man and it is certainly to be appreciated if we can bring before the public the fact that speed costs money. The telephone message being largely intangible, the general public is apt to get the idea that it does not make any difference in your cost of operation whether you get the connection through quickly or slowly. The telephone user is liable to forget the simultaneous demands of the many other telephone users. This paper brings out evidence of the practical necessity of lining up the toll calls in the order of receipt, if rates and earnings on the plant investment are to be reasonable. Every toll telephone plant representing a large investment may be likened to a transmission plant subject to very high peak loads. A large part of the day the plant is not carrying anywhere near its capacity and at other parts of the day it may be subject to overload demands. Unfortunately these busy or overload periods occur at the hour when business is at its height and thus at the time when speed means the most to the patron.

Again, with our telephone toll plant the revenue is based on the productive time. Furthermore, with each short period of production we must necessarily have a nonproductive time during which the circuit must be built up from the calling party to his correspondent. It is as though we had a power transmission line, the revenue from which is derived from the number of minutes of useful production of a motor load at one end, it being necessary to stop and start both generator and motor, free of charge, before and after each useful run. It is very evident that the less this nonproductive time, especially at busy periods, the greater the number of messages that can be handled. Mention is made in the paper of the single-ticket and two-ticket methods. The former method cuts down the nonproductive time and gets the business over the line more quickly. However, with the two-ticket method there is a record of the message at two points and thus there is less liability of losing track of completed calls.

The paper calls attention to the fact that with a certain average speed of service, some of the calls will be handled considerably more slowly than the average. This is clearly shown by comparing the curves in Fig. 2 and Fig. 4. The middle curve of Fig. 4 represents approximately 40 messages per circuit. Now if you will observe curve 2, you will find that at this rate the average speed of service as shown by the abscissa is 12 minutes, while the maximum delay shown on the middle curve of Fig. 4 is some 30 minutes, or two and one-half times this. It is well recognized that speedy service is a good advertisement and results in the filing of many messages which would not otherwise be offered. In devising a telephone toll plant we must continually have in mind the proper balance between (1) the number of messages to be handled, that is, number of paid minutes per day, (2) the necessary speed of service, (3) practicable rates, and (4) the corresponding number of circuits required, that is, the plant investment.

Presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Spokane, Wash., September 9, 1914.

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THE EFFECT OF DELTA AND STAR CONNECTIONS UPON TRANSFORMER WAVE FORMS

LESLIE F. CURTIS

ABSTRACT OF PAPER

The purpose of the paper is to show the distortions resulting from different symmetrical three-phase connections of generator and transformers without transmission line, as dependent upon the hysteresis cycle and the admittance of the transformers at no-load.

Tests were made with the oscillograph to show the no-load exciting current and voltage waves of three single-phase step-up transformers when the windings of the generator and both sides of the transformers were connected in all possible symmetrical delta and star relations.

Tests are divided into four groups, according to the connection of the generator. In all cases normal low-tension line voltage was held, but voltage and current measurements were considered less important than the recording of wave forms.

Oscillograms are given in each case and the relations between the flux, voltage, exciting current, and the hysteresis cycle are shown in two instances.

The author points out that the best voltage wave forms will, in general, be obtained with a star-connected generator and delta-star or star-delta connected transformers.

INTRODUCTION

It is well known that the method of connecting three-phase transformers, or single-phase transformers upon three-phase lines, influences the character of the potential and current waves, in that the type of connection limits the per cent of the harmonics of e.m.f. which may appear between lines and the per cent of the harmonics of current which may appear in any line. It is not the purpose of this paper to bring forth any new discoveries, but to present a series of wave forms, taken with the oscillograph, showing the wave distortions which are likely to occur in the different symmetrical three-phase connections.

Oscillograms of potential and exciting current were taken at no-load upon three single-phase, 10-kw., 1100-110-volt, 60-cycle step-up transformers when connected in all possible combinations of delta and star. The generator used was a 7.5-kw., 60-cycle machine, so arranged as to give the desired voltages when connected either delta or star. It was thought that any distortions would be a maximum with the large transformers connected to the smaller generator at no-load.

Throughout all of the tests the line voltage was held at 110 when the transformers were connected in delta, and at 110 $\sqrt{3}$ when the transformers were connected in star.

Since the transformers were very nearly balanced, wave forms were not recorded upon all of the phases.

TESTS WITH ONE TRANSFORMER

Before investigating the wave forms with the three-phase connections, an oscillogram of exciting current with a sine wave of e.m.f. was taken to determine the hysteresis cycle under normal conditions. This is shown in Fig. 1.

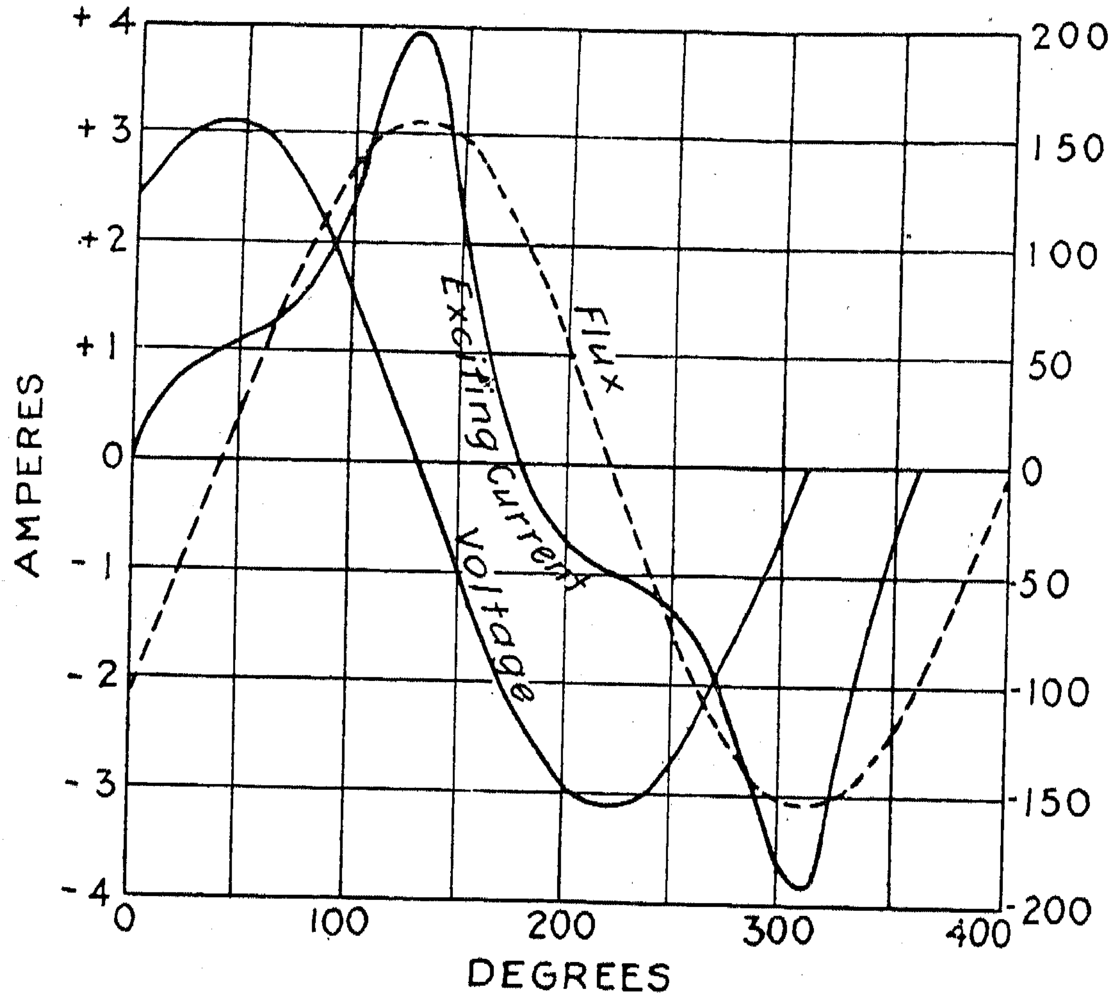


FIG. 2—POTENTIAL, FLUX AND CURRENT WAVES. SINGLE-PHASE CONNECTION

Fig. 2 shows the voltage, flux and exciting current, and Fig. 3 the resulting hysteresis cycle scaled from the original oscillogram.

TESTS WITH STAR-CONNECTED GENERATOR

The next set of tests was run with the generator connected in star. This gave practically a sine wave of e.m.f. between lines, except when the reactions in the transformers introduced a fifth harmonic.

With a star-star connection of transformers, the wave of exciting current is as in Fig. 4. Since no third harmonic can exist in the exciting current, one must appear in the transformer voltage, or the voltage to neutral, even though the line voltage remains a sine wave, because of the definite shape of the hysteresis cycle. This is shown in Fig. 5.

Fig. 6 shows the voltage, flux and exciting-current relations for the above connection. The hysteresis cycle is plotted in Fig. 3, showing the same general shape as for the sine wave of flux, but being smaller in area.

For the above test, normal line voltage (110 $\sqrt{3}$ volts) was held, but owing to the change in wave shape, the voltage to neutral was 121.0.

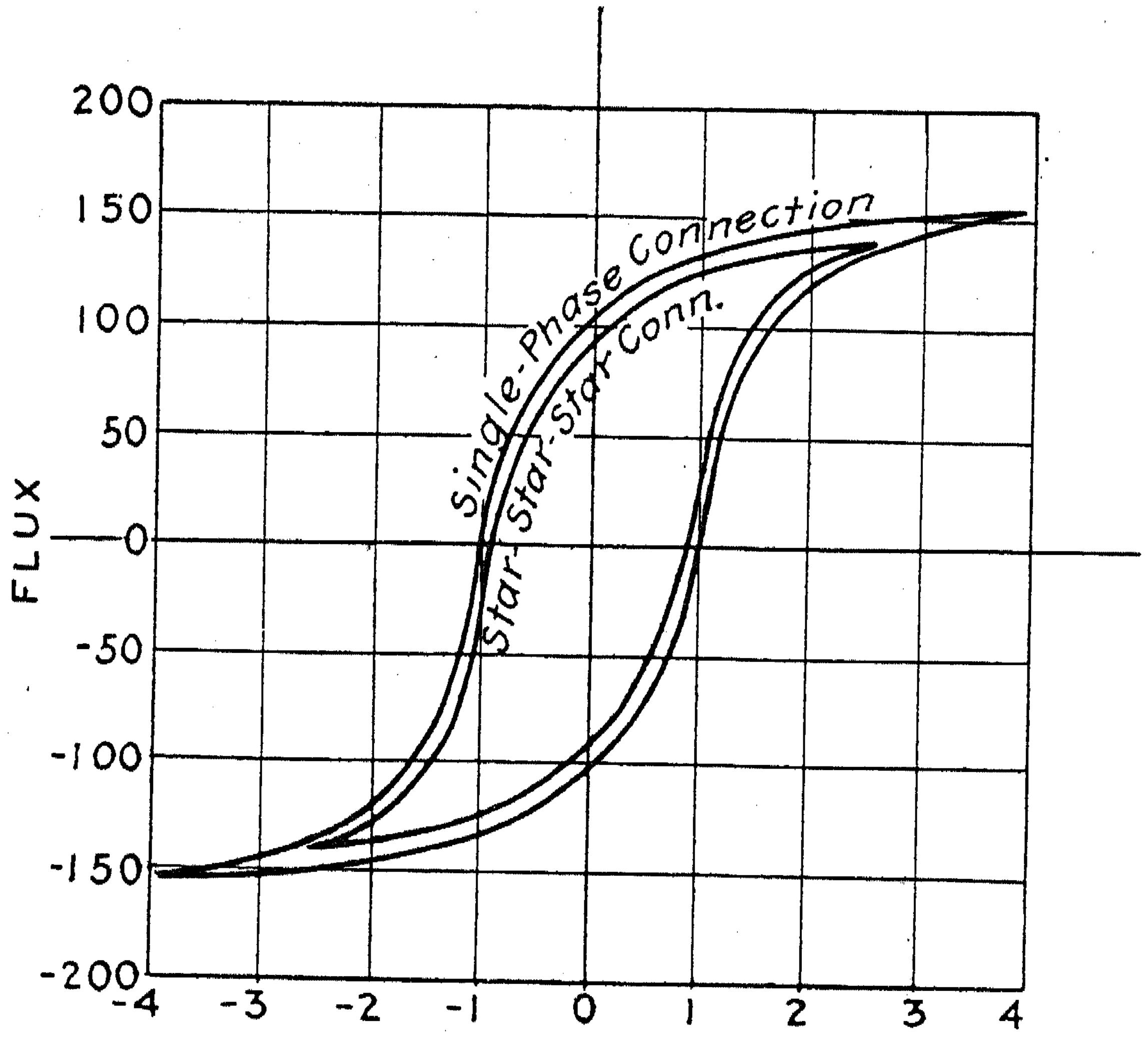


FIG. 3—HYSTERESIS CYCLES

With one side of the transformers connected in delta, the third harmonic, which is lacking in the exciting current with the star-star connection, may flow in the closed delta. It appears only in the local transformer circuit. Fig. 7 shows the line current and the transformer current for a delta-star connection of windings. The admittance of the transformers is such that a fifth harmonic in excess of the amount demanded by the hysteresis cycle appears in the line and transformer currents. This causes a fifth harmonic to appear in the e.m.f.

waves, as is shown in Fig. 8. Curve 2 shows the characteristic flat-topped delta voltage, or high-tension voltage to neutral, for this connection. Curve 1 shows the high-tension line voltage, which is peaked because of the vector difference of waves containing the fifth harmonic similar to that shown in Curve 2, 120 deg. apart.

It will be noted that the reaction causing this distortion originates in the transformers, since the wave of exciting current

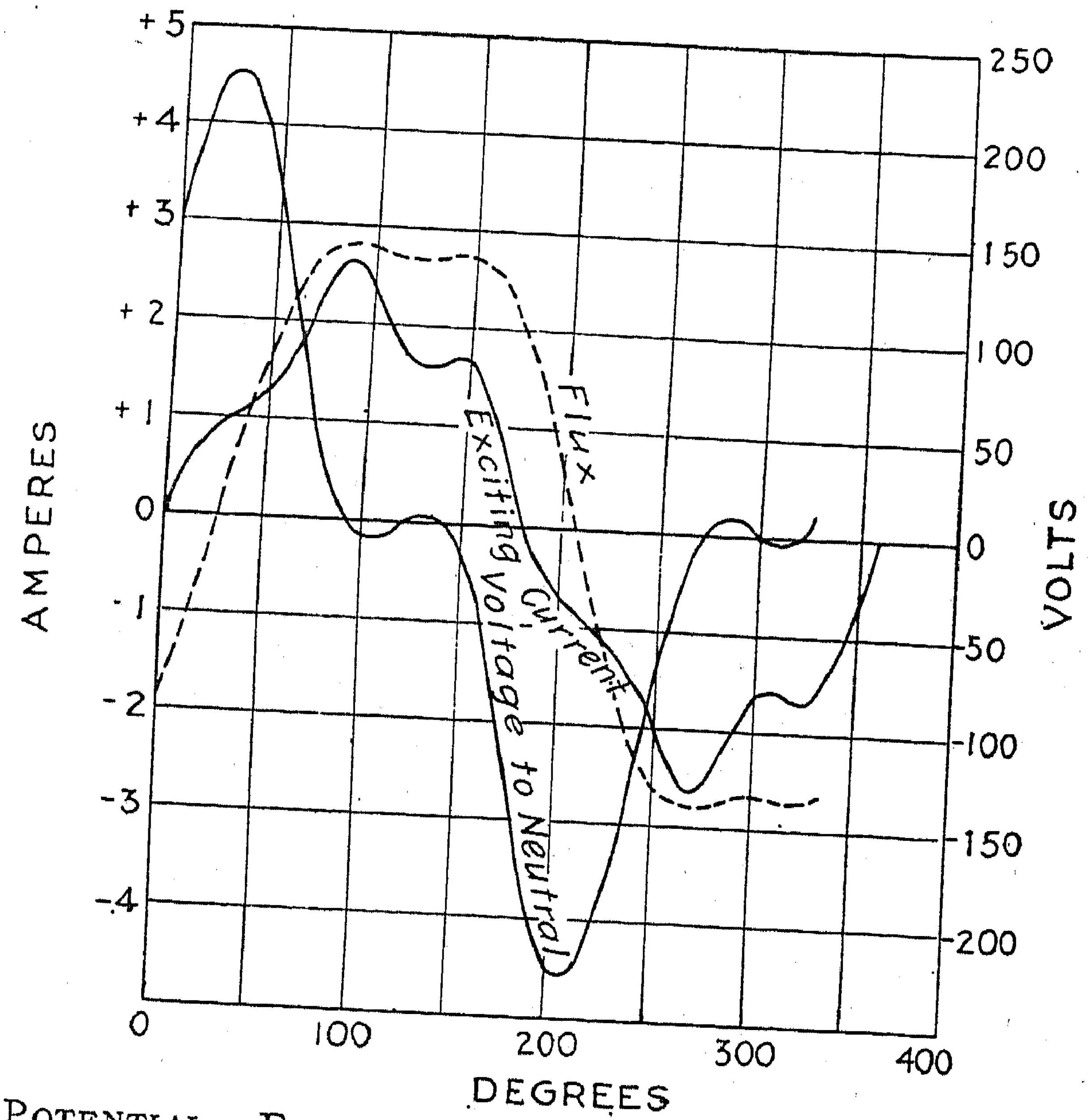
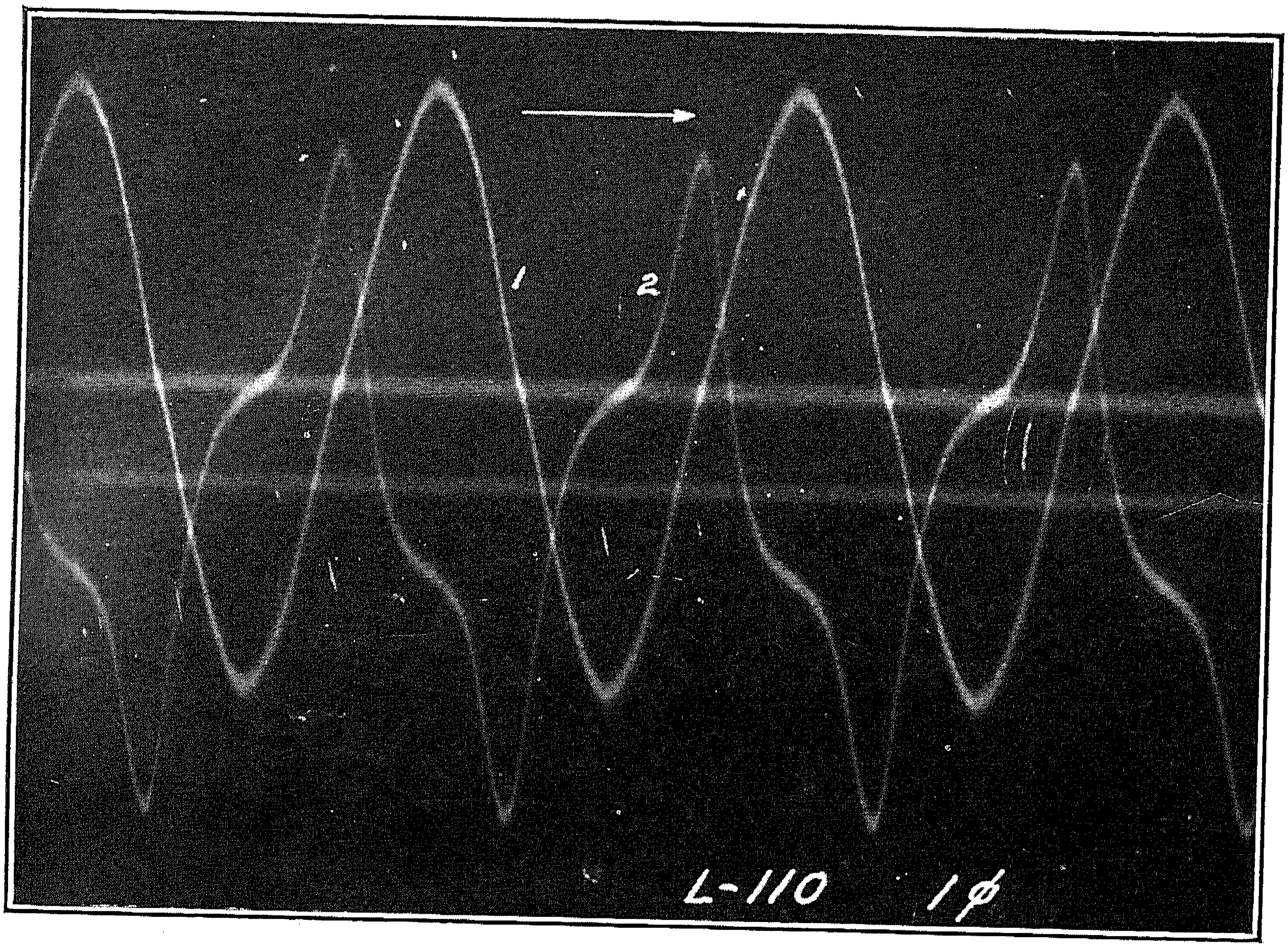


FIG. 6—POTENTIAL, FLUX AND CURRENT WAVES. STAR-STAR-STAR CONNECTION

is not materially different from that of the star-star connection which did not distort the generator voltage.

Fig. 9 shows the exciting currents for a star-delta connection of transformers. The third harmonic of the exciting ampere-turns is now derived from the high-tension delta circuit. The low-tension line current contains an excess of the fifth harmonic as in the previous case, causing the same flat-topped wave of voltage to neutral or delta voltage as before. The transformer and line voltages are given in Fig. 10.

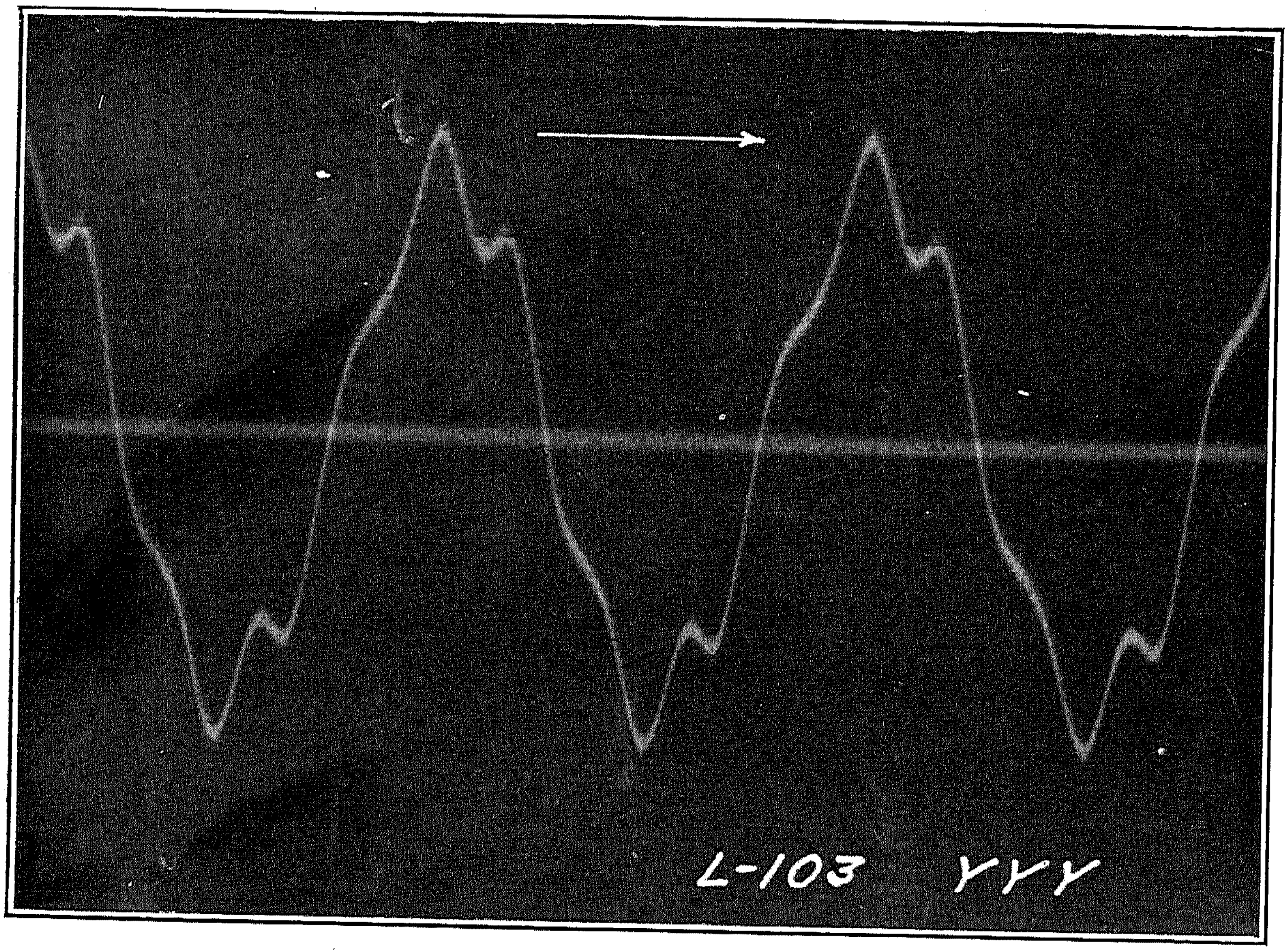
For a delta-delta connection of transformers, the voltage distortions are apt to be increased, due to the troublesome



[CURTIS]

Fig. 1—Exciting Current and Potential Waves

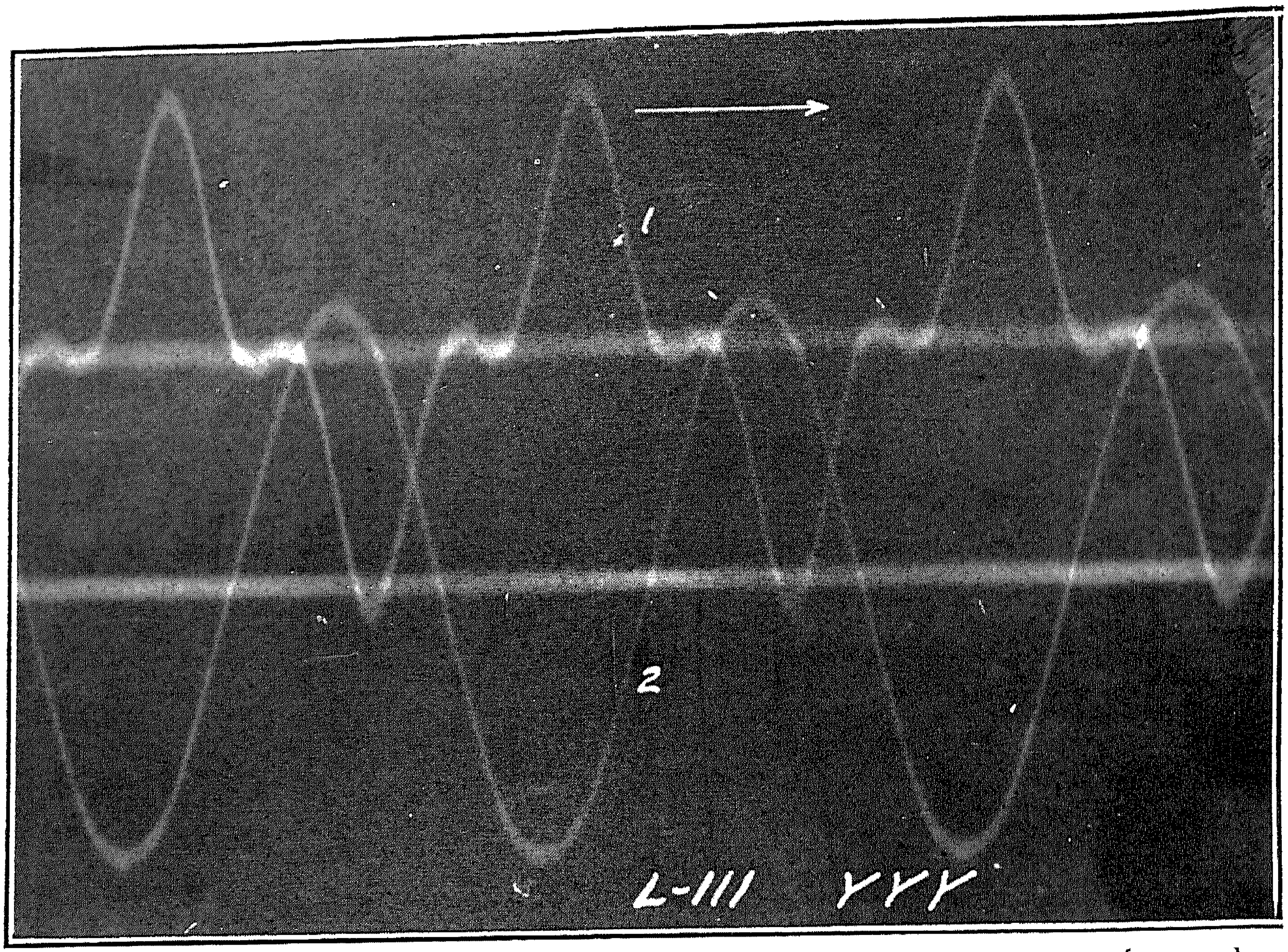
Single-phase connection. Curve 1, voltage across transformer, 110.0 volts. Curve 2, exciting current, 2.00 amperes.



[CURTIS]

Fig. 4—Exciting Current Wave

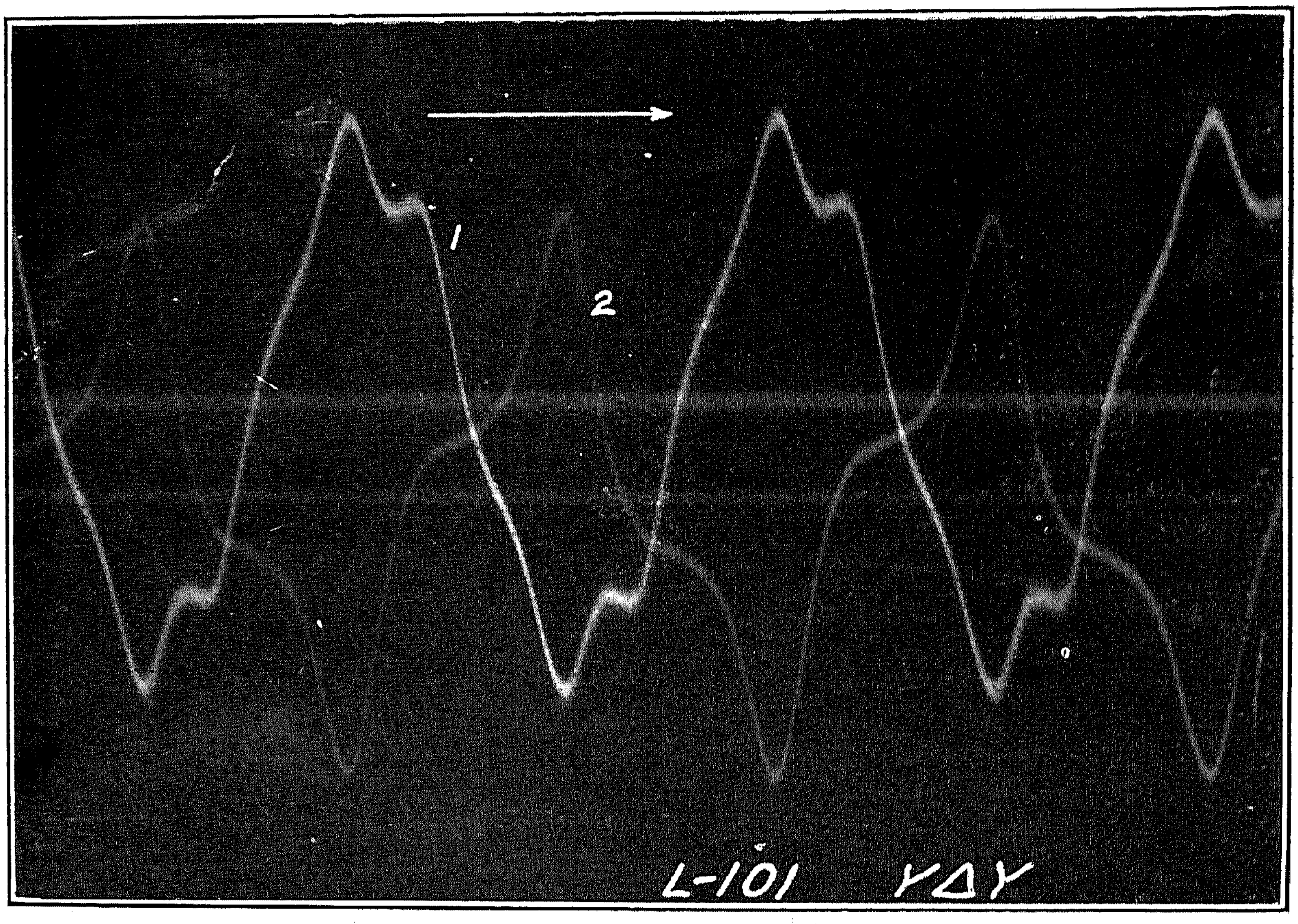
Star-star-star connection.



[CURTIS]

FIG. 5—POTENTIAL WAVES

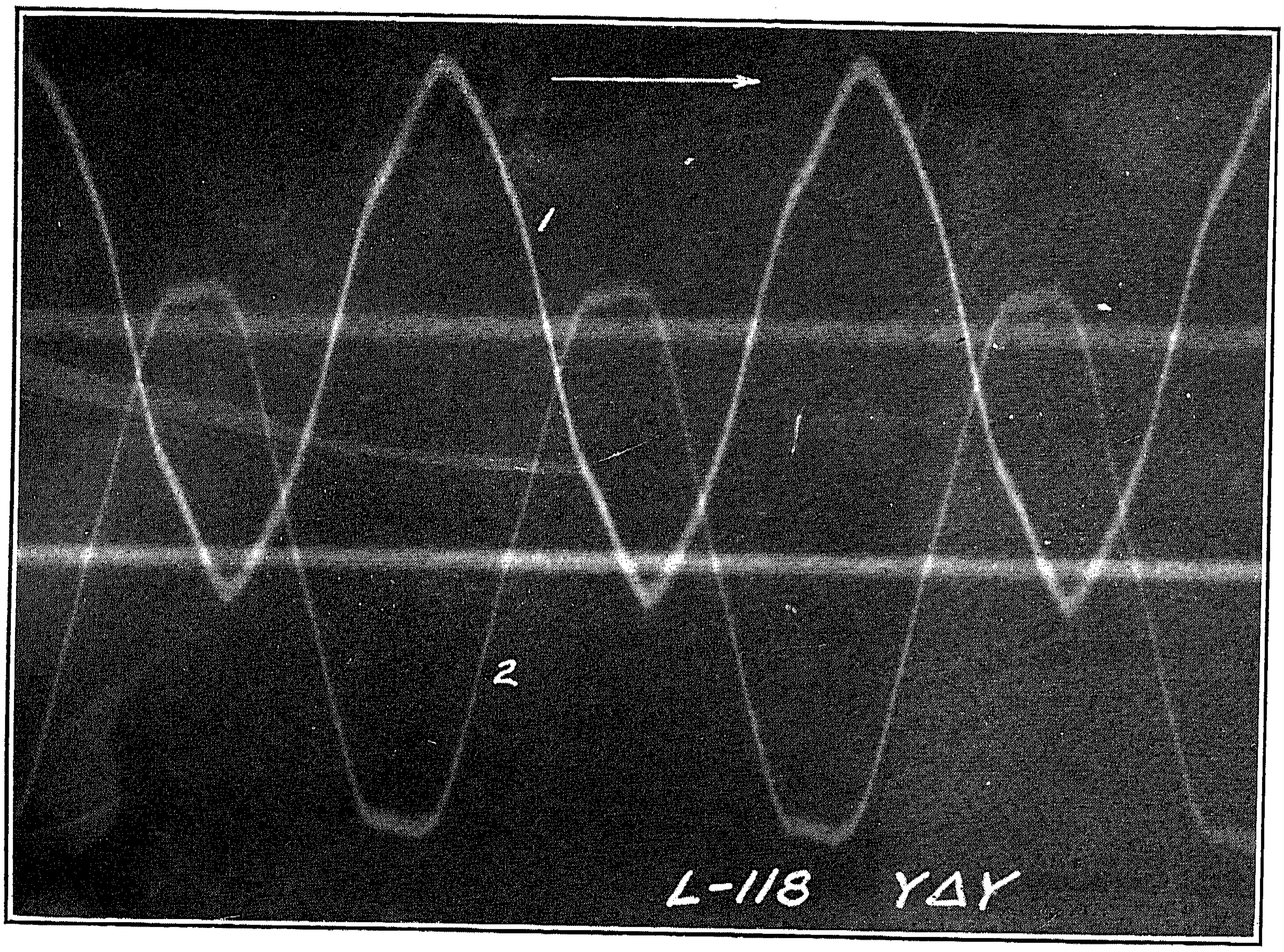
Star-star-star connection. Curve 1, voltage to neutral, 121.0 volts. Curve 2, voltage between lines, 190.3 volts.



[CURTIS]

FIG. 7—EXCITING CURRENT WAVES

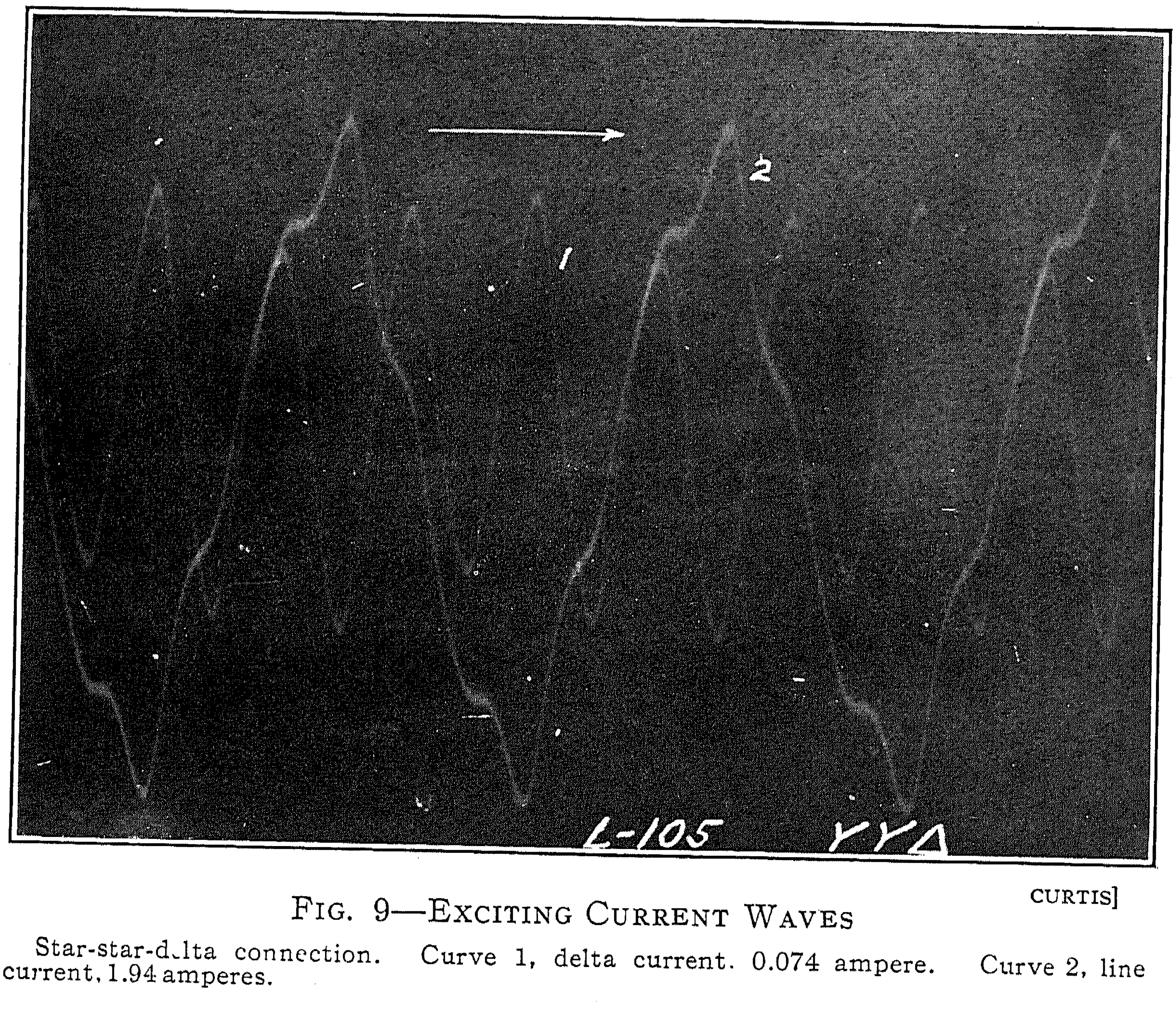
Star-delta-star connection. Curve 1, line current, 3.39 amperes. Curve 2, transformer current, 2.11 amperes.



[CURTIS]

FIG. 8—POTENTIAL WAVES

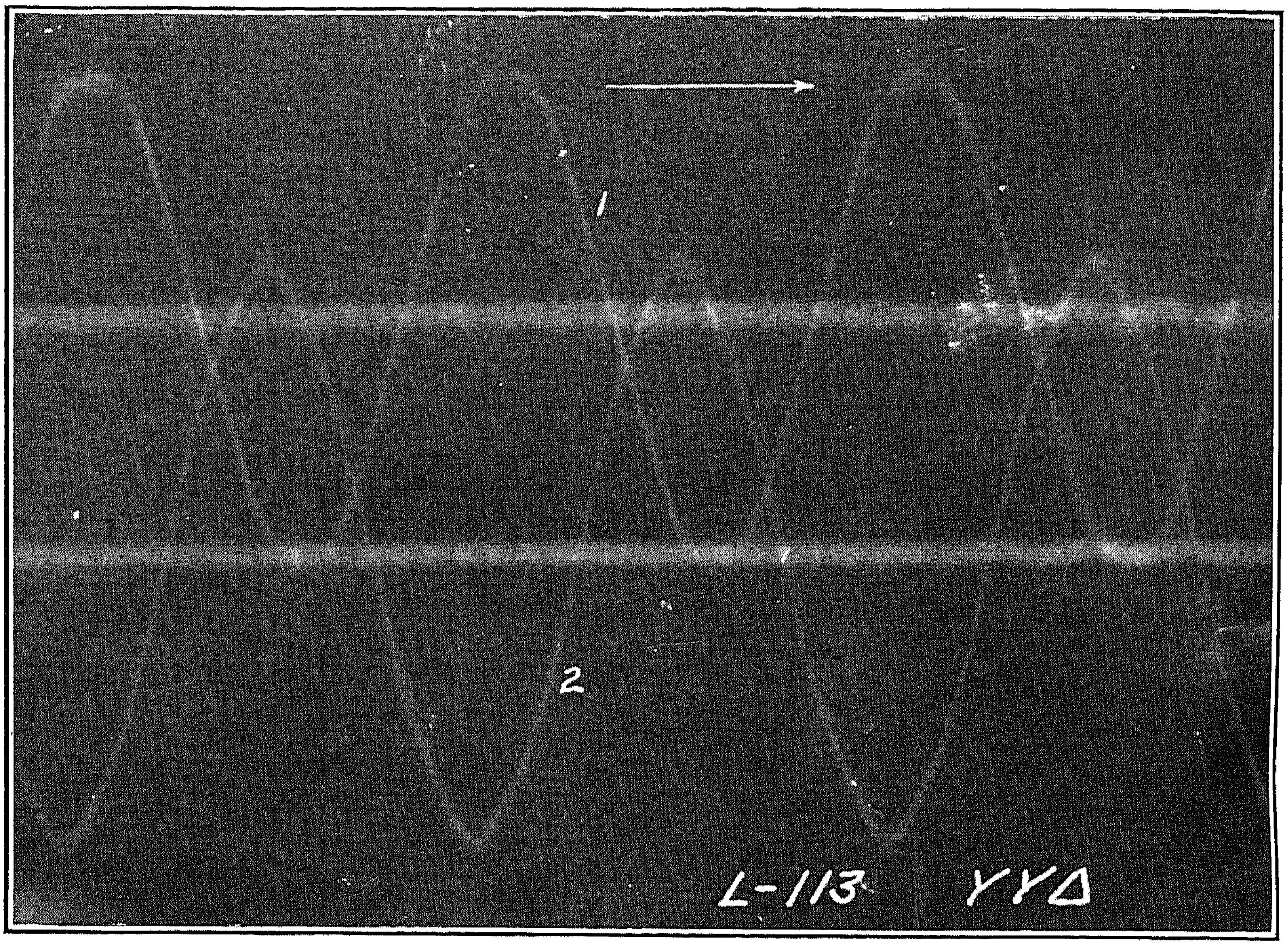
Star-delta-star connection. Curve 1, line voltage 1924.0 volts. Curve 2, delta voltage 110.0 volts.



CURTIS]

FIG. 9—EXCITING CURRENT WAVES

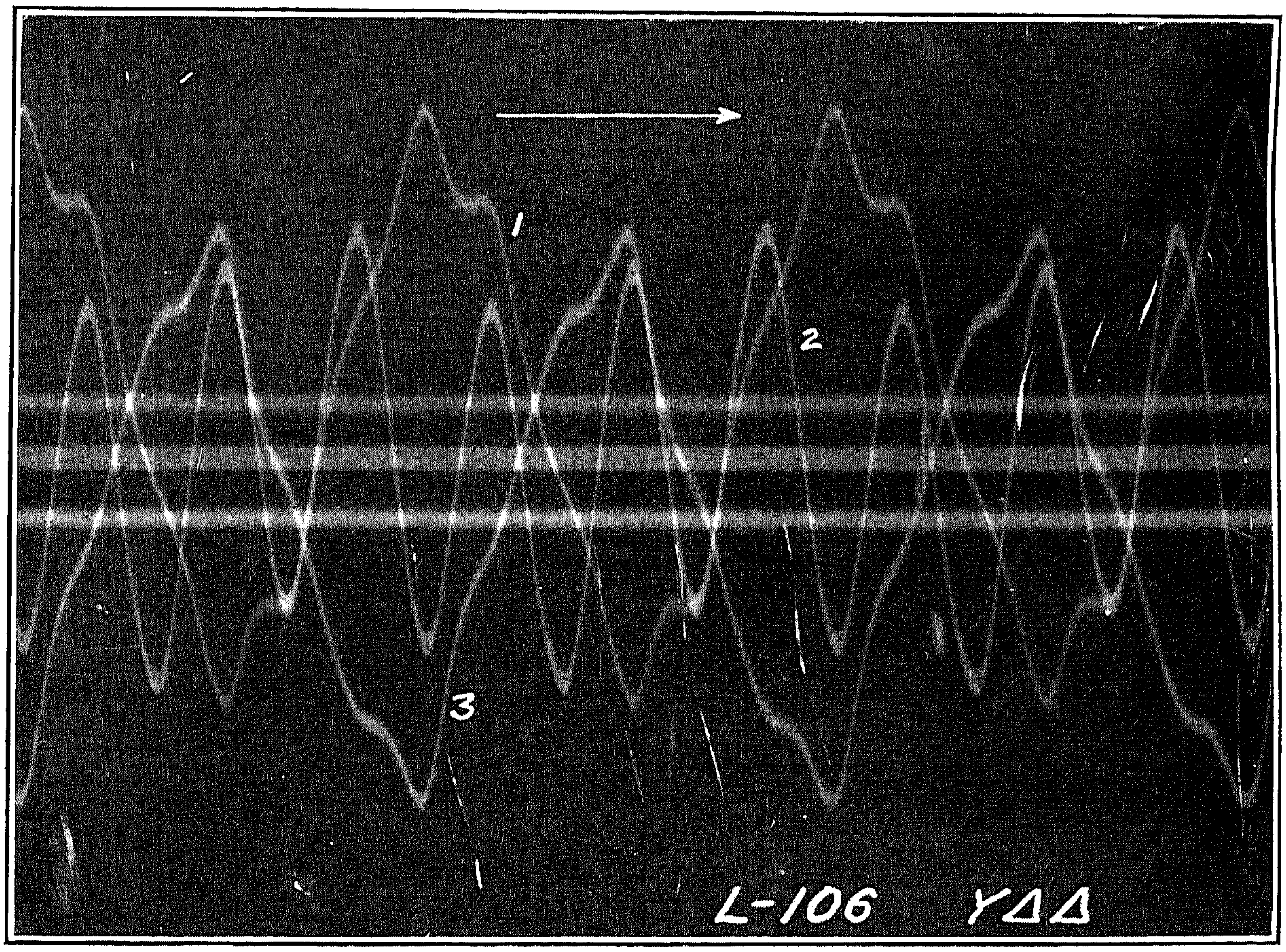
Star-star-delta connection. Curve 1, delta current. 0.074 ampere. Curve 2, line current, 1.94 amperes.



[CURTIS]

FIG. 10—POTENTIAL WAVES

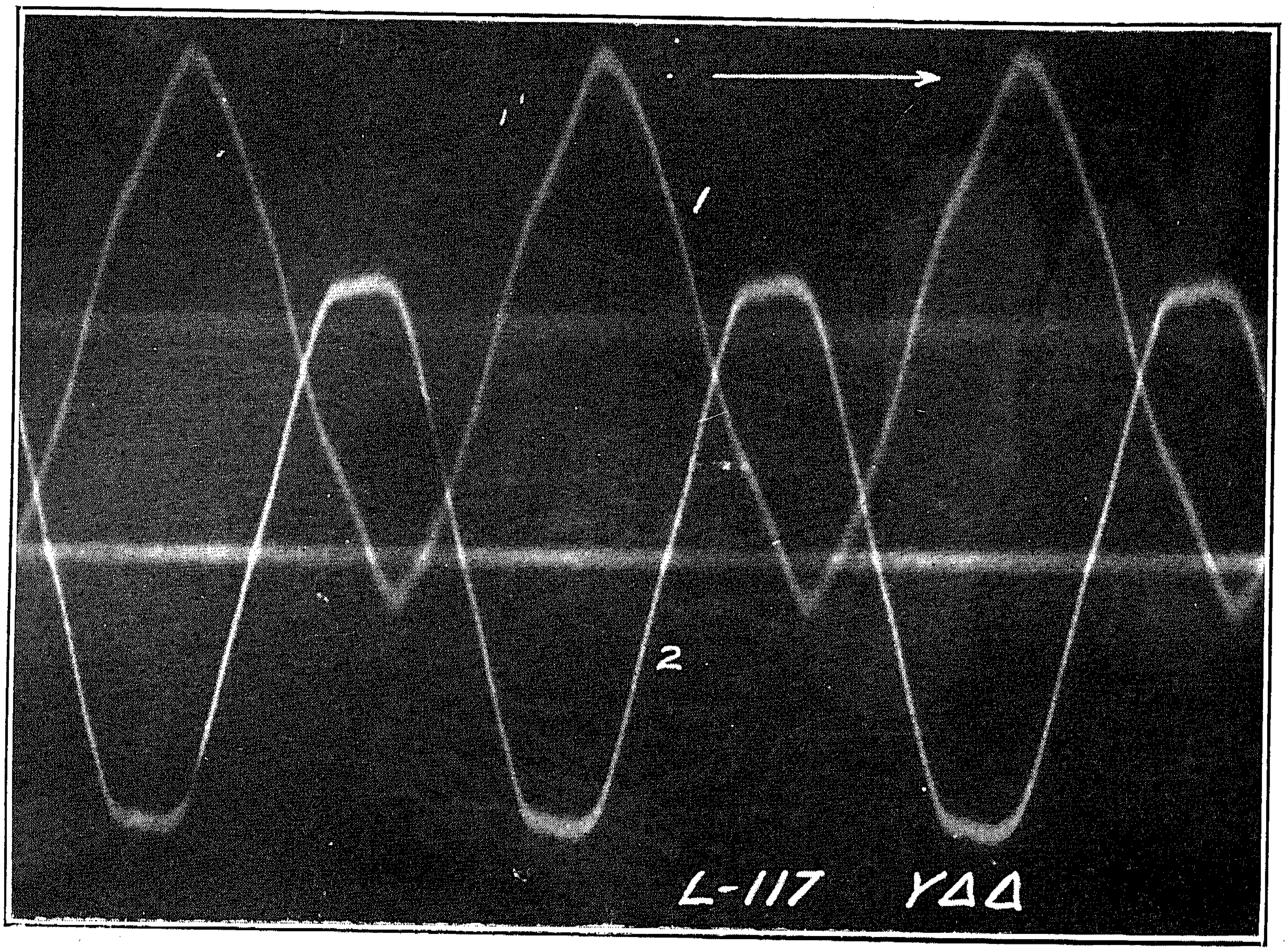
Star-star-delta connection. Curve 1, voltage to neutral, 110.0 volts. Curve 2, line voltage, 190.3 volts.



[CURTIS]

FIG. 11—EXCITING CURRENT WAVES

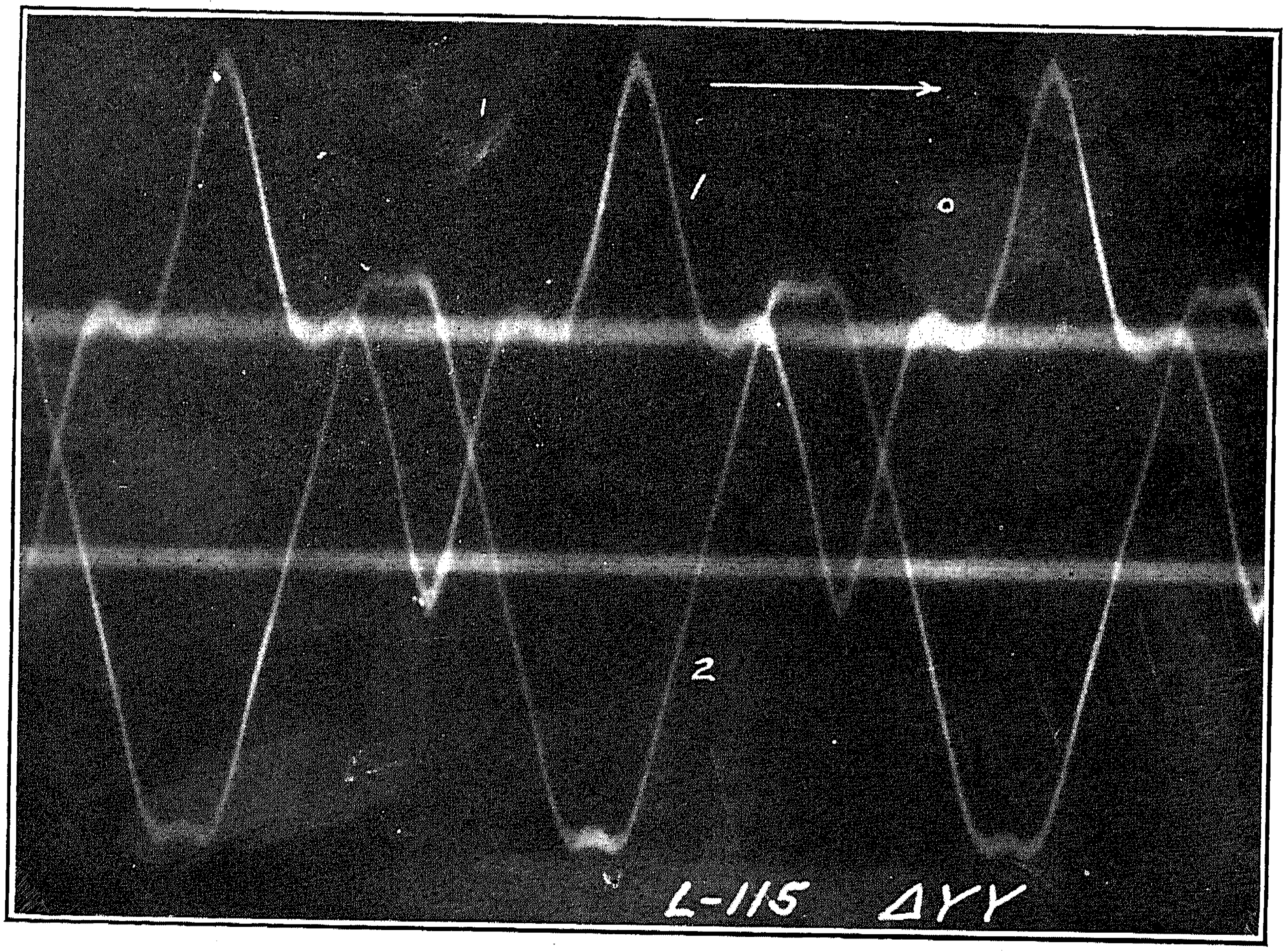
Star-delta-delta connection. Curve 1, line current, 3.49 amperes. Curve 2, high-tension delta current, 0.068 ampere. Curve 3, low-tension delta current, 2.15 amperes.



[CURTIS]

FIG. 12—POTENTIAL WAVES

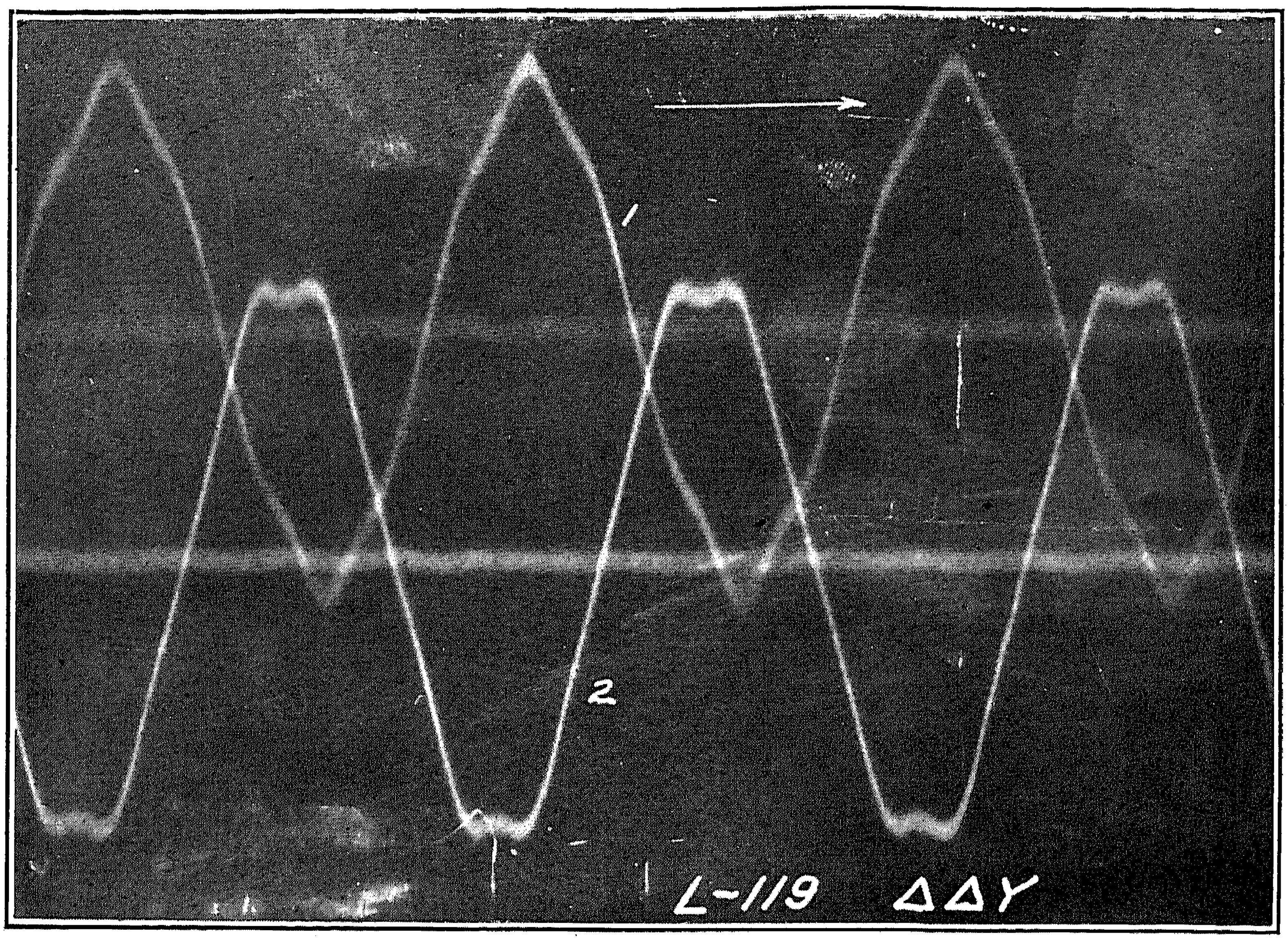
Star-delta-delta connection. Curve 1, voltage to generator neutral, 63.8 volts. Curve 2, line voltage, 110.0 volts.



[CURTIS]

FIG. 13—POTENTIAL WAVES

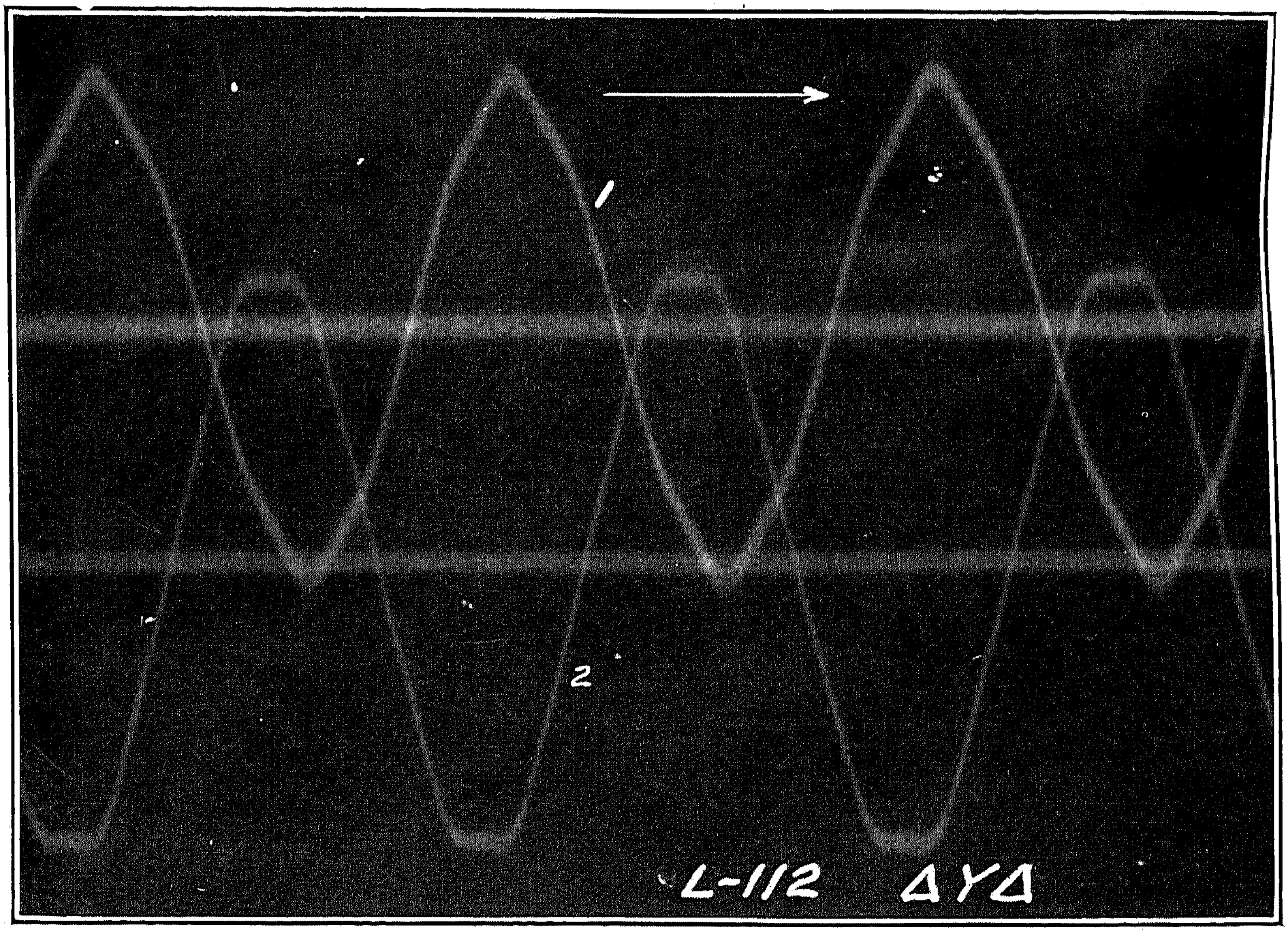
Delta-star-star connection. Curve 1, voltage to neutral, 121.1 volts. Curve 2, line voltage, 190.3 volts.



[CURTIS]

FIG. 14—POTENTIAL WAVES

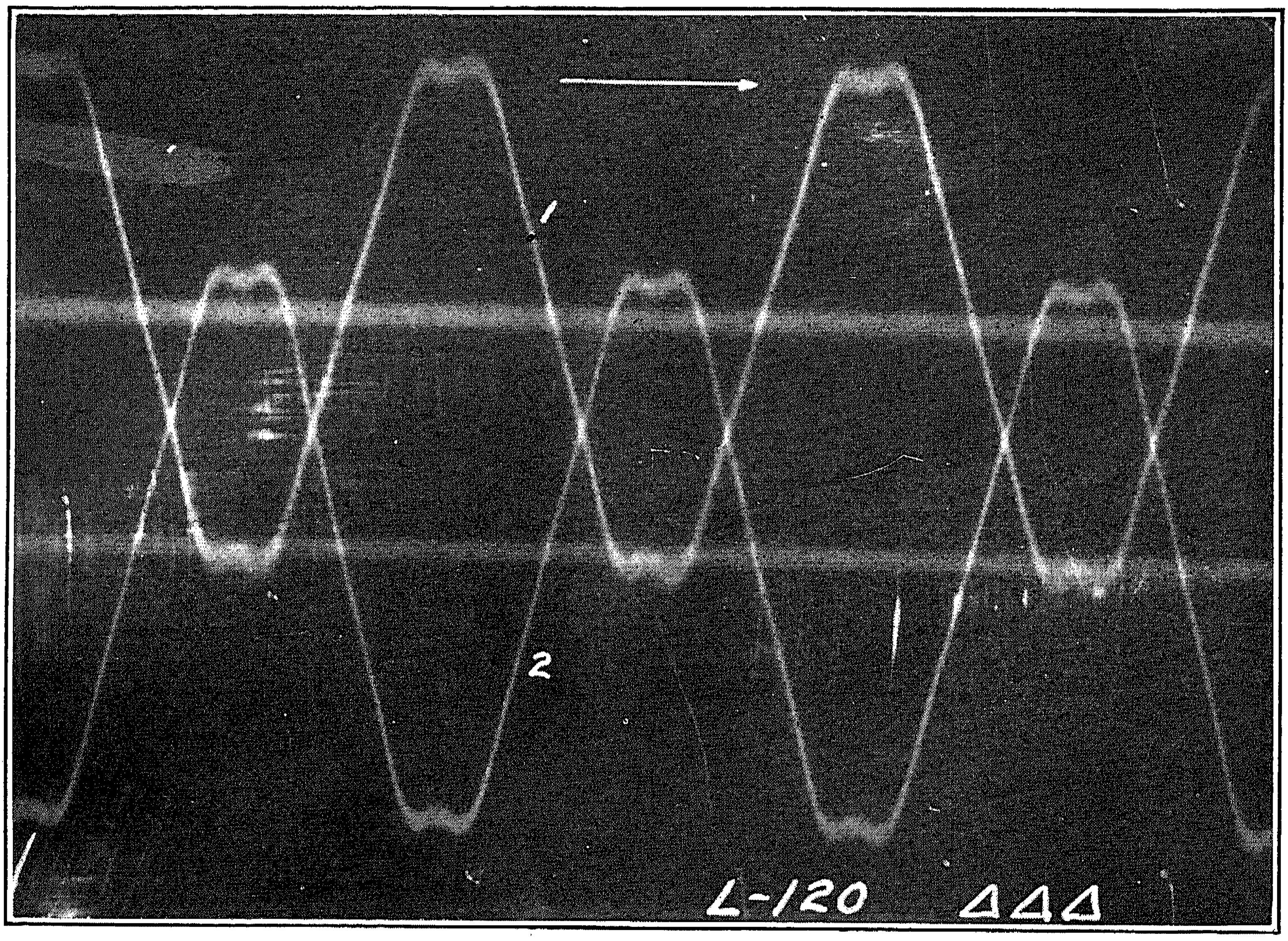
Delta-delta-star connection. Curve 1, line voltage, 1930.0 volts. Curve 2, delta voltage, 110.0 volts.



[CURTIS]

FIG. 15—POTENTIAL WAVES

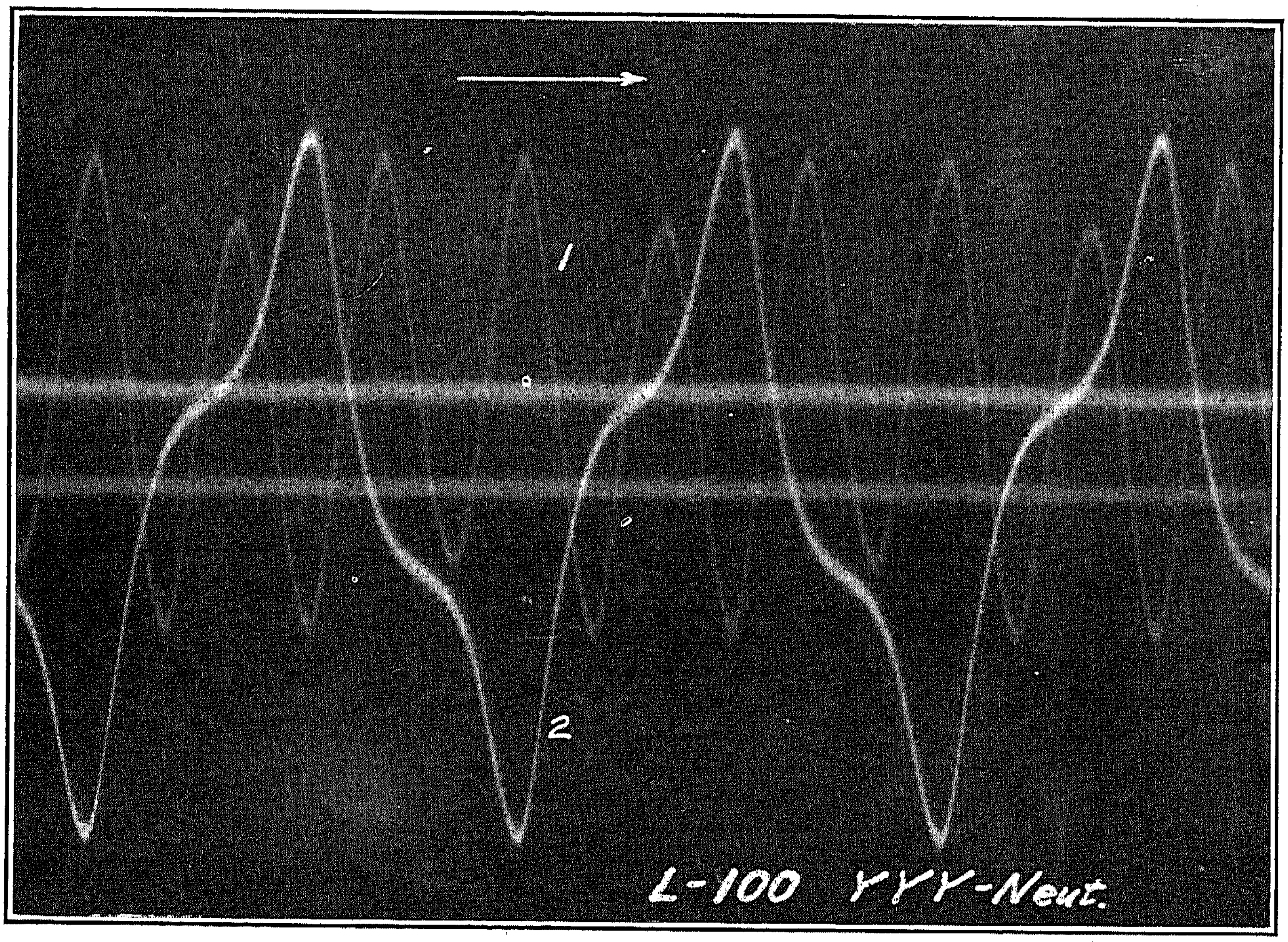
Delta-star-delta connection. Curve 1, voltage to neutral, 110.1 volts. Curve 2, line voltage, 190.3 volts.



[CURTIS]

FIG. 16—POTENTIAL WAVES

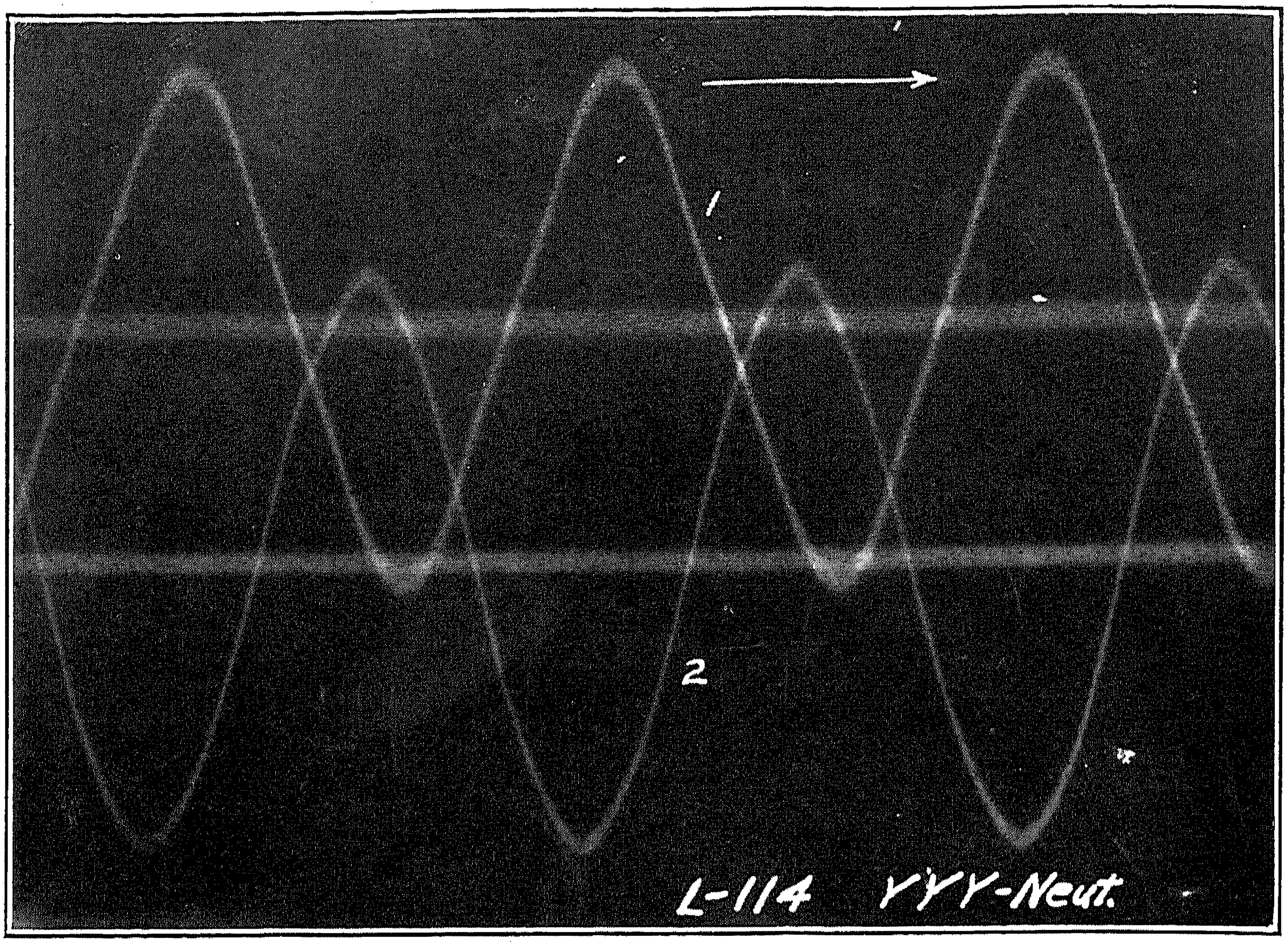
Delta-delta-delta connection. Curve 1, low-tension voltage, 110.0 volts. Curve 2, high-tension voltage, 1110.0 volts.



[CURTIS]

FIG. 17—EXCITING CURRENT WAVES

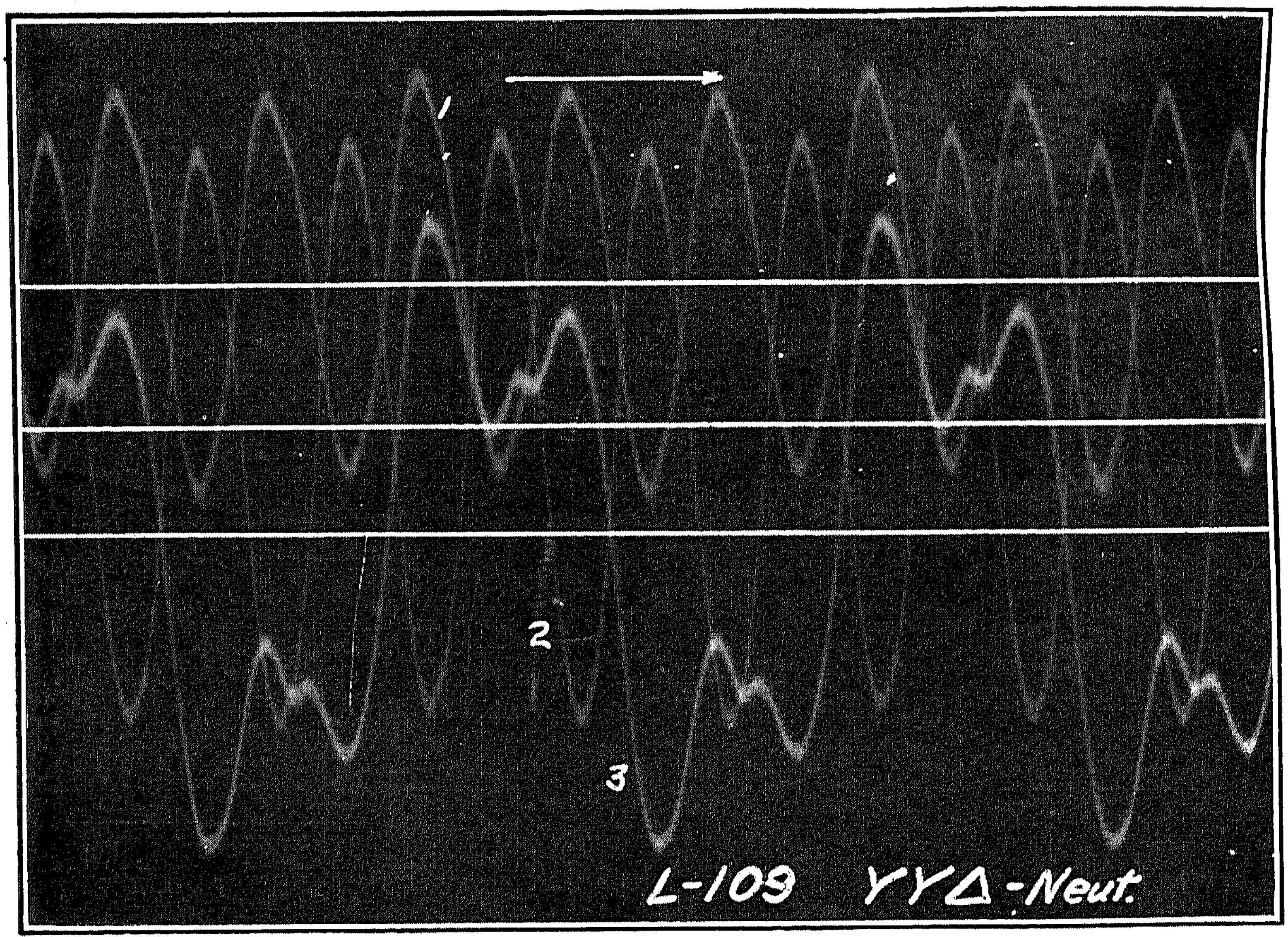
Star-neutral-star-star connection. Curve 1, neutral current, 1.83 amperes. Curve 2, line current, 1.99 amperes.



[CURTIS]

FIG. 18—POTENTIAL WAVES

Star-neutral-star-star connection. Curve 1, voltage to neutral, 110.6 volts. Curve 2, line voltage, 190.3 volts.



[CURTIS]

FIG. 19—EXCITING CURRENT WAVES

Star-neutral-star-delta connection. Curve 1, neutral current, 3.55 amperes. Curve 2, delta current, 0.186 ampere. Curve 3, line current. 2.23 amperes.

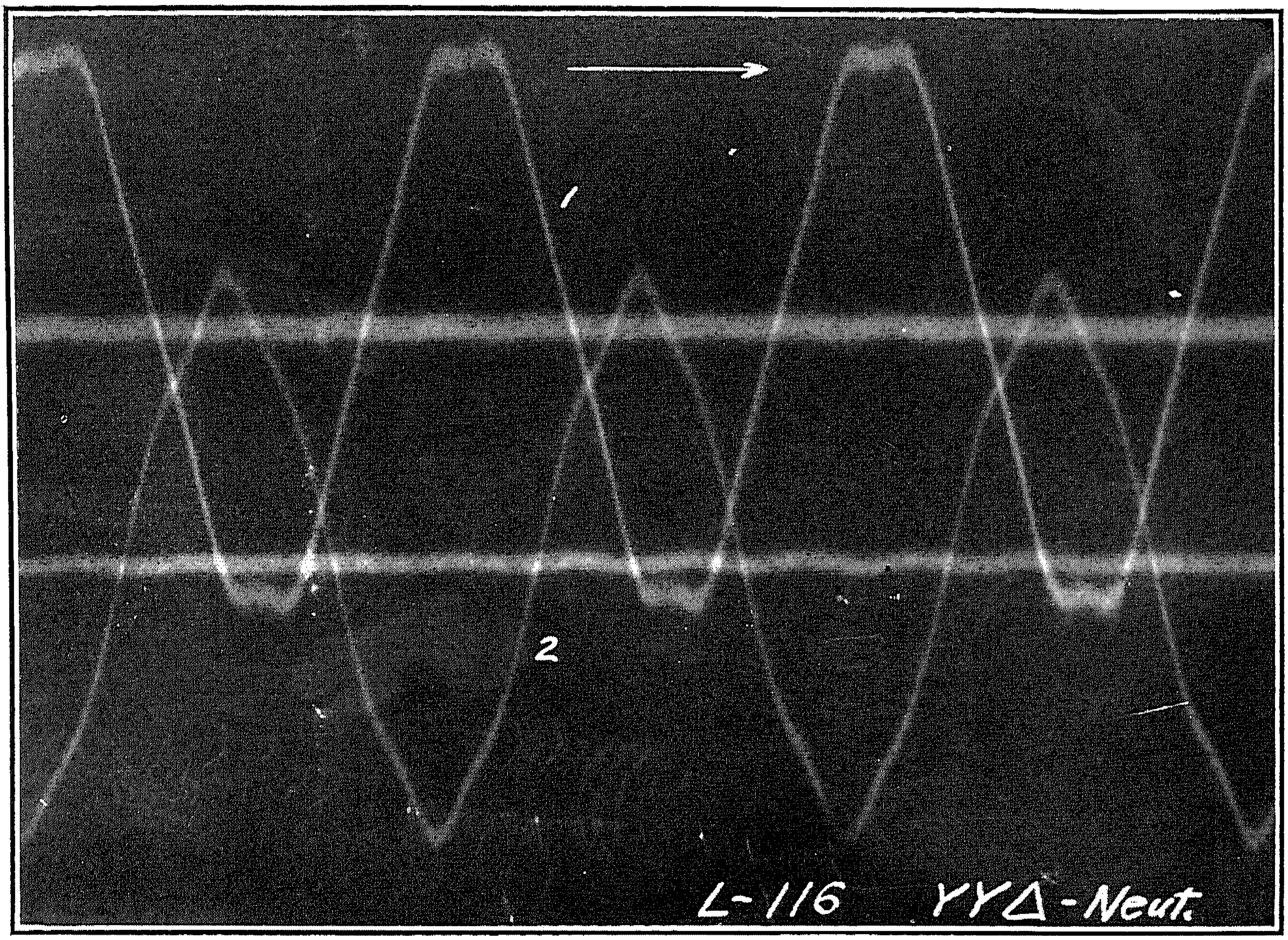


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FIG. 20—POTENTIAL WAVES

Star-neutral-star-delta connection. Curve 1, voltage to neutral, 110.2 volts. Curve 2, line voltage, 190.3 volts.

fifth harmonics in the exciting circuits. The currents and voltages for this connection are shown in Figs. 11 and 12.

Tests with Delta-Connected Generator

With the generator connected in delta, the short-circuit third harmonic current in the armature produces a pulsation at six times the normal frequency in the field flux, which, in turn, introduces a fifth and a seventh harmonic in the armature voltage. Of these, the fifth is the more troublesome, producing the familiar flat-topped wave of delta voltage.

Distortions due to the transformer connections are superimposed upon the generator wave. Figs. 13, 14, 15 and 16 show the voltages of the banks of transformers connected in star-star, delta-star, star-delta and delta-delta respectively, when excited from the delta-connected generator. The original wave form of the generator voltage is shown in Fig. 13, since the star-star connection of transformers does not distort the line voltage.

Tests with Connected Neutral

When the generator and the low-tension side of the transformers are connected in star with connected neutral, the third harmonic components of the exciting current may return to the generator over the neutral, each phase constituting a single-phase circuit.

The waves of exciting current for a star-star bank of transformers with connection to the generator neutral are shown in Fig. 17. The voltages are shown in Fig. 18, being very nearly sine waves.

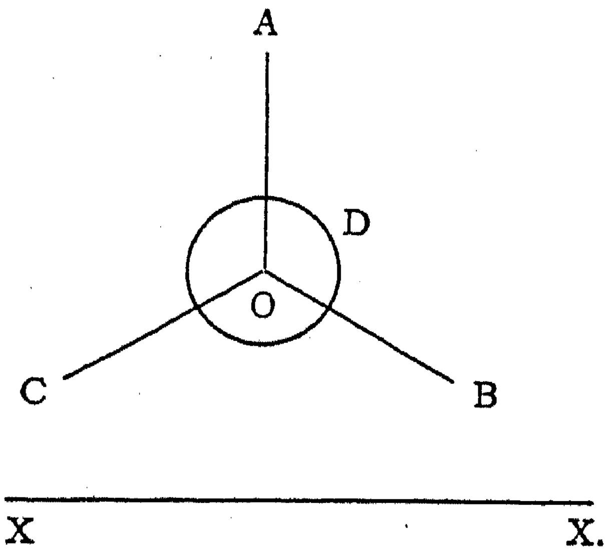
If the high-tension side is now placed in delta, there exists a short circuit of the unbalanced third harmonics in the three transformers. This causes an excessive third-harmonic current to flow over the neutral which reacts upon the generator flux in the same way as that in a delta-connected generator. This is shown in Fig. 19. A flat-topped wave of voltage to neutral and a peaked line voltage result, as shown in Fig. 20.

Preferable Connections

From the above results it is seen, from the standpoint of wave form, that the banks of transformers connected delta-star, star-delta, or star-star with connected generator neutral give the best results. The latter connection would be ruled out if dissimilar banks were to be operated in parallel.

DISCUSSION ON "THE EFFECT OF DELTA AND STAR CONNECTIONS UPON TRANSFORMER WAVE FORMS" (CURTIS), SPOKANE, WASH., SEPTEMBER 9, 1914.

P. M. Lincoln: We may represent a three-phase system as in this diagram, in which the figure *ABC* may be assumed to rotate around its center *O*. The instantaneous voltages will then be proportional to the lengths of the projections upon a line, as *XX*. For instance, at the instant represented in the figure the instantaneous voltage of leg *AO* is zero, that of phase *CB* is a maximum, and those of phases *AB* and *AC* are each one-half of the maximum, one increasing and the other decreasing.



If we so represent a three-phase system, we will find that a third harmonic in the leg voltages *OA*, *OB* and *OC* will have the effect of causing the neutral point *O* to rotate around the small circle *D* and the rate of rotation of the neutral around this small circle will be three times that of the whole system around *O*. For instance, if we assume that the point *A* has advanced 10 deg., during the same time the neutral will have advanced 30 deg.

The diameter of the small circle *D* is dependent upon the amount of third harmonic that enters the leg voltages *OA*, *OB* and *OC*. It is evident from this analysis that we may have any amount of third harmonic voltages in these leg voltages without having any third harmonic voltages in the phase voltages *AB*, *AC* or *BC*. This physical conception has enabled me to see this problem more clearly than otherwise and I pass it on for what it is worth.

L. J. Corbett: The paper appeals to me as a very valuable one and one which requires a great deal of study. It brings to light some very interesting problems and I think this idea as given out by our president is very valuable. It is a new one to me. I thought at first he was referring to the unbalancing of load which has the effect of shifting the neutral on this three-phase triangle.

A. A. Miller: It seems to me that this question is open for discussion by the representatives present of the faculties of the several universities and also by the operating engineers. The effect of the oscillograph upon the ability which we have to diagnose these cases is very marked. Some half-dozen years ago there was absolutely nothing of the kind to assist us; the effects of the higher harmonics were guessed at and such results as were acquired, were obtained by means of curves which were plotted more or less from a theoretical basis. By means of this highly sensitive instrument which we now have, we can see exactly what goes on in these circuits.

E. G. Robinson, Jr.: What results are gotten with open-delta connections? I think that is a connection that a great many of us are using to start with on our transformers for power and light; and the question arises in my mind, what is really taking place in your transformers regarding the circulating currents, the triple harmonics and the circulating current in the delta where this delta is open; were these secured with a delta closed or the delta with one side open? I start with an open delta in my transformers and as my load increases, or my power load increases, I close my delta. I would like to have the author answer that question regarding the circulating currents when using transformers with open delta.

M. H. Gerry, Jr.: The old question has arisen of the relative advantages of delta and star connections for power transformers. No general conclusion has ever been reached in this matter, nor is there likely to be any definite answer, as there is no one controlling condition or set of conditions. Certain practises have arisen which have worked well in particular situations. In other places different practises have seemed best. There are so many things to be considered that, after all, the question is one of general expediency.

L. T. Merwin: Along the line of a suggestion already hinted by Mr. Gerry I ask Mr. Curtis, in closing, to answer this question—What form of connection is advisable from the standpoint of the operating engineer for protection of the transmission line beyond the power house, say for voltages ranging from 60,000 and up? The operating engineer is particularly interested in wave forms as well as circulating currents at two points, one between the generators and transformers at the power house and the other between transformers and line. And then again, what bearing has the wave form upon the breakdown point of his transmission line after it has passed beyond the power house? Will the star-delta or the star-star or the delta-star connection give the safest form of wave curve on the line from the standpoint of the breakdown? It is that which interests particularly the operating engineer. Mr. Curtis shows his oscillograph curves with transformer connections open on the high side; but with load on the end of a 150-mile high-tension transmission line, what changes in the wave form will take place as against an open transformer bank?

Livingston P. Ferris: I ask Mr. Curtis to cover the following points in his closure: Just what wave form is considered in the comparisons upon which you base your conclusion? By what criterion do you judge the distortion of wave form characteristic of the different types of connections? Have you followed the recently adopted standardization rules of the Institute or some other standard?

I will mention two circuit arrangements for oscillograms which have been found useful in the investigation of the Joint Committee on Inductive Interference in California. These circuit arrangements are designed to distort the wave form of current through the vibrator, magnifying the higher harmonics in this wave as compared with their relative magnitude in the desired main line current or voltage wave. For current waves, the secondary of a current transformer is closed through a low-impedance air-core inductance coil, the constants of one such coil being $1.12 + j\, 0.0468\, f$ ohms. Around this coil is shunted the vibrator of the oscillograph in series with a condenser and rheostat. The amplitude of the wave and magnification of the harmonics in the vibrator current are controlled by adjustment of the condenser and rheostat in series with the vibrator. An analysis of the vibrator wave expressed in current units, together with a knowledge of the circuit constants, enables one to compute the value of the main line current corresponding to any harmonic. Care is necessary with this arrangement, in order that the impedance in the secondary of the current transformer shall not be too high and particularly that the circuit shall not resonate at or very near the frequency of some harmonic which it is desired to measure. For voltage waves, the vibrator is connected in series with a condenser and rheostat and supplied from a potential transformer. By these methods of accentuating the higher harmonics the accuracy of their determination in the current and voltage waves is much increased.

H. V. Carpenter: I would like to enlarge a little on the point that Mr. Curtis brought out, that the various connections which he dealt with give different losses in the transformer cores. That would have some bearing in determining the capacities of these different connections, the load capacities. It might be possible if Mr. Curtis has given the matter any thought to tell us something about the amount of increase in rating that might be considered possible in certain cases over that of other connections. It would seem from the hysteresis diagrams which he showed that there might be sufficient saving in core losses there to make it appreciable in the load capacity of the transformer sets.

L. F. Curtis: As to Mr. Robinson's question regarding the open delta, I regret that I have no oscillograms for this connection. I will predict that there will be an unbalance of voltage between the three phases. There could be no third harmonic in any current flowing over a balanced three-phase line, but if there is an unbalance, as would be the case with open delta excitation, there might be a diversity of third harmonic components in the different lines. This would probably produce a reduction of voltage across the open phase, causing the voltage triangle to become distorted, the shortest line representing the voltage across the open side. It would also be probable that the wave forms of voltage of all three phases of the two transformers would be different. It is quite probable that if one wave were flat the others would be peaked.

As to Mr. Merwin's question: Papers which were presented at Pittsfield made similar reference to the subject from a practical standpoint. From my observations, the wave forms are the best upon the lines with the star connection of transformer windings and connected generator neutral, but this connection is possible only when the transformer banks are not operated parallel with others of different characteristics. If such parallel operation were attempted, as has been in some cases, circulating currents between the banks would flow over the neutral, causing heating which should be prevented. It appears to me that the best connection would be a star-connected generator, delta-connected low-tension circuit, and star-connected high-tension circuit, with possibly a grounded neutral, the advantages of which were pointed out in the papers presented before the Institute at Pittsfield in May. The wave forms for this connection are good.

We know that an inductive load tends to flatten the higher harmonics and that the wave forms with the inductive load would then be much better than without it. The most serious disturbances would probably occur on an unloaded line, because of the fact that the capacity of the lines exaggerates the higher harmonics in exact proportion to their order in the charging current. If we have, for instance, an eleventh harmonic on the line of say ten per cent. it appears in the charging current or capacity current as ten times eleven or 110 per cent, so that upon the line open at the far end we would expect the greater distortion and the most trouble from the higher harmonics. During switching we may have other disturbances due to the fact that the three phases are not closed simultaneously, and as noticed from the experience on the California lines, less trouble from switching seems to be caused when a grounded neutral with a star-connected high-tension circuit is used.

As to the criterion for judging wave forms: I have not used the American Institute standard because it tells nothing of the order of the harmonics. In analyzing the waves, I have kept a record not only of the effective and maximum values of each wave, but the per cent and order of each harmonic, so that due weight might be given to the harmonics of higher order. I might say that in these investigations, none above the fifth was objectionable. I used the connection suggested by Mr. Ferris, that of the condenser in series with resistance for exaggerating the harmonics in the voltage waves. Upon the generator used, the fifth was the only noticeable higher harmonic in the voltage wave. The tests were run throughout without any transmission line connected, so that effect of capacity in the high-tension circuit may be neglected. It was a no-load test throughout.

As to the higher rating of the star-star-connected transformers because of the change in core loss, I think that this rating would be affected very little and would not be the criterion. In the star-star connection the core loss is only a small percentage less than for single-phase. The rating of the transformer would be slightly greater, but on account of the objectionable voltage to neutral, the connection would probably be ruled out in any case.

It is to be regretted that the paper is incomplete in that the author has been unable to deal with the wave forms of three-phase transformers. With three-phase shell-type transformers, the results would be very similar to those obtained with the three single-phase units, but with three-phase core type units, the wave shapes would be considerably changed.

Since the recording of wave-shape was considered to be of prime importance, no special care was taken to calibrate or correct meter readings. Portable instruments of the electrodynamometer type were used for voltage readings. For the measurement of potential upon the high-tension windings a potential transformer was introduced. Care was taken to disconnect all potential-reading-instruments before taking current oscillograms. While the tests were not made with great scientific accuracy, uniform conditions were maintained throughout, making the results in the different cases comparable.

Presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Spokane, Wash., September 10, 1914.

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150,000-VOLT TRANSMISSION SYSTEM

SOME OPERATING CONDITIONS OF THE BIG CREEK DEVELOPMENT OF THE PACIFIC LIGHT & POWER CORPORATION

BY EDWARD WOODBURY

ABSTRACT OF PAPER

The paper describes operating conditions on the 150,000-volt transmission line of the Pacific Light and Power Corporation which delivers power from the Big Creek hydroelectric development to Los Angeles, Cal., 240 miles away. In daily operation 60,000 kw. are generated, utilizing a total hydraulic head of 4000 ft., in two steps. Plans for the future contemplate the building of two more power houses, operating under somewhat lower heads.

Of particular interest is the complete success of the constant potential system, *i. e.*, operation at the same voltage at the generating and receiving stations, by means of synchronous condensers at the receiving end, in conjunction with automatic voltage regulators, one for each condenser as well as for the generators at each of the power houses. The line has been operated with unusual freedom from short circuits.

Appendixes describe the development of the system, and give data relating to the equipment of the Big Creek transmission line.

THE most striking feature of the Big Creek development and transmission is the magnitude of the figures in which the plant data are expressed. In daily operation, 60,000 kw. are generated, utilizing a total hydraulic head of 4000 ft. (1219 m.) in two steps, and transmitted 240 miles (386 km.) at 150,000 volts, thus entailing some conditions of operation which are rather striking.

The transmission line is of course the element of greatest importance in satisfactory commercial operation, although there are many features of engineering interest in the generating and receiving parts of the system.

The most critical problem to be solved proved to be that of regulation. It must be remembered that the inherent regulation of the line alone, without terminal equipment, is from 10 per cent above power house voltage at no load, to 20 per cent below at full load; that the effect of the transformer inductive reactance at the generating end practically doubles the boosting at light load, and that the self-exciting characteristics of the generators, when supplying charging current only, tend to produce abnormal voltages at light load.

The complete success of the constant potential or zero regulation system, *i.e.*, operation at the same voltage at the generating and receiving stations, is of particular interest. This result is obtained by the use of synchronous condensers at the receiving end, in conjunction with automatic voltage regulators, one for each condenser as well as for the generators at each of the power houses. Since there are two 15,000-kv-a. condensers and four 17,500-kv-a. generators to be controlled, the regulator problem received most serious consideration, and was made the subject of careful experiment under working conditions before being proved satisfactory, as it now is. It has been found necessary to arrange the regulators to control field currents from a maximum to zero.

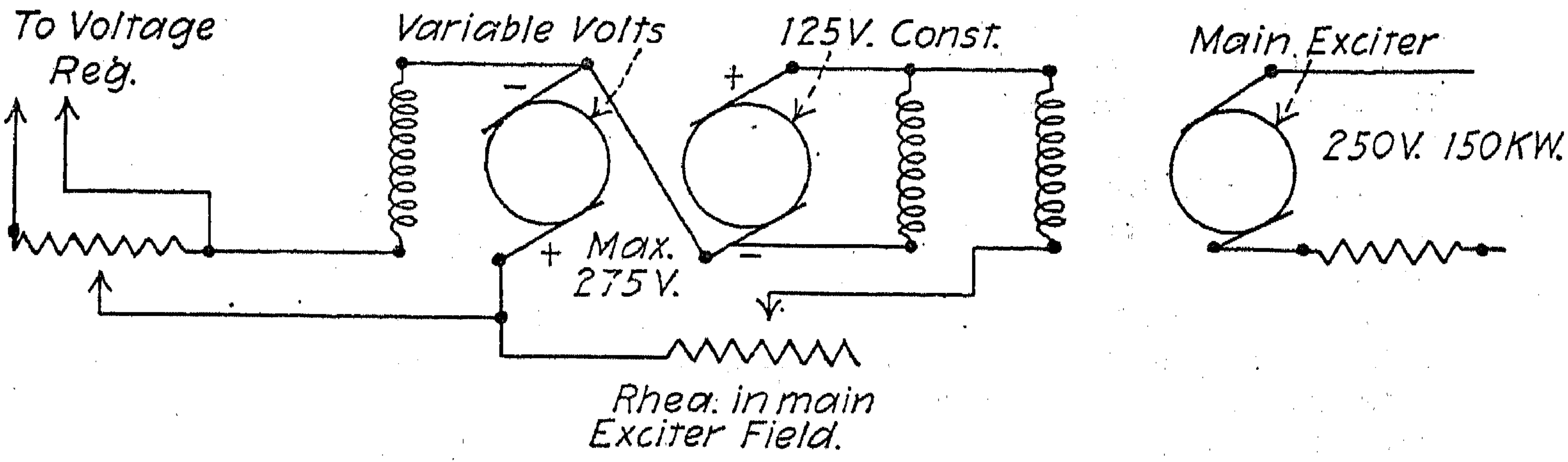


FIG. 1—EXCITER CONNECTION, PLANT NO. 1, BIG CREEK.

In one generating station the excitation system consists of three direct-current units, one of which is the exciter proper, the other two being connected in series opposition, and used to excite the field of the main exciter. See Fig. 1. The two units making up the secondary exciter are designed to generate 125 volts and 275 volts respectively. With a potential regulator on the 275-volt unit, arranged with auxiliaries to prevent a reversal of the field in the 125-volt unit of this set, the voltage applied to the exciter field may be changed from that required to give maximum excitation to zero excitation, within a range of voltage on the 275-volt unit which can be readily handled by the standard alternating-current automatic voltage regulator.

The alternators at the other generator station are excited directly by 200-kw., 250-volt exciters, the main field of which is controlled by a new type of alternating-current automatic voltage regulator, which has no direct-current magnet and which can therefore be adjusted to reduce the exciter voltage to zero. The exciters on this system have three shunt windings on the field, as shown in Fig. 2. One auxiliary field is provided to give the reversed excitation necessary to hold the voltage down when charging the line, the current being supplied to this field, through a variable resistance, by means of a storage battery. The other auxiliary field, which is solely for the purpose of maintaining the correct polarity, also takes its current, which is small, from the same storage battery.

A reduction of the excitation to zero by means of the potential regulator, has not been necessary at the generating stations, but operation of the synchronous condensers at the receiving station, over the range required, would not be feasible without a complete reduction of the exciter voltage.

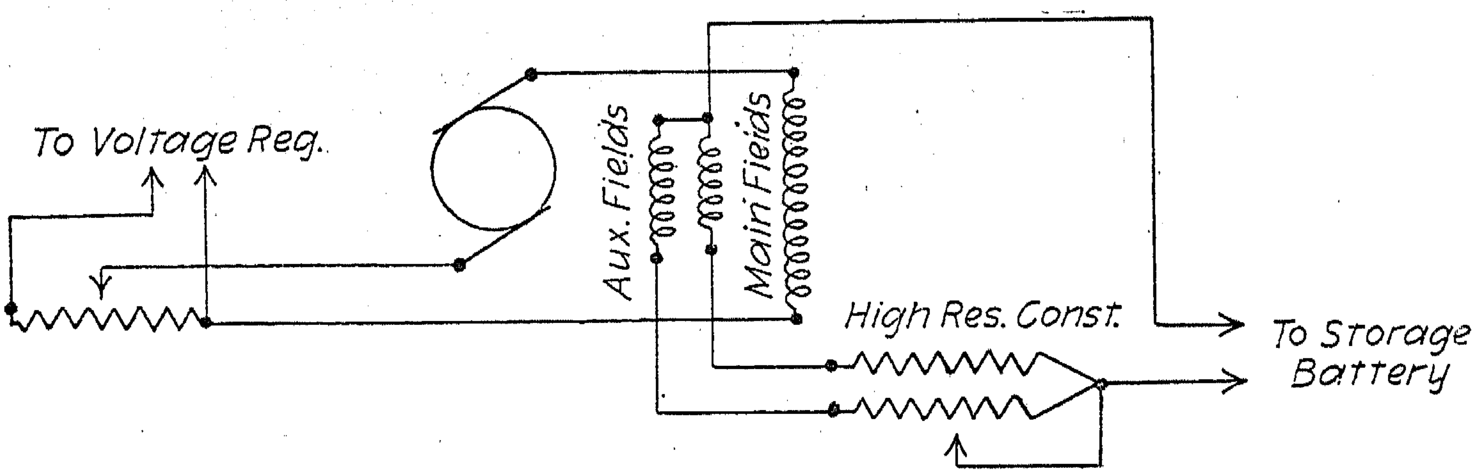


FIG. 2—EXCITER CONNECTION, PLANT NO. 2, BIG CREEK.

With 150,000 volts at the receiving end of the line, the charging current is about 40 per cent overload for one generator. With normal voltage of 6600 volts at the generator, the charging current overloads the generator 65 to 70 per cent. Hence in normal operation a line is usually energized by using two generators, under which condition a small field excitation in the normal direction is required. Abnormal conditions sometimes make it necessary to charge the line from a single generator, until the condensers at the receiving station can be started.

The self-exciting characteristics of the system with leading current are such that in one of the generating stations a single 6600-volt generator, when connected to an unloaded line without its condenser and run at normal speed with the field switch open, would excite itself to 7600 volts, corresponding to 190,000 volts on the transmission line at the generating station, and demand from the generators 35,000 kv-a. and 3000 actual kilowatts.

At the other station, where the generators were designed by a different manufacturer and had slightly different characteristics, the results were greater and the self-excitation under similar conditions would reach 9000 volts at the generator or 230,000 volts on the line at the generating end. For this condition the generator would have to deliver 5000 kw. and about 50,000 kv-a.

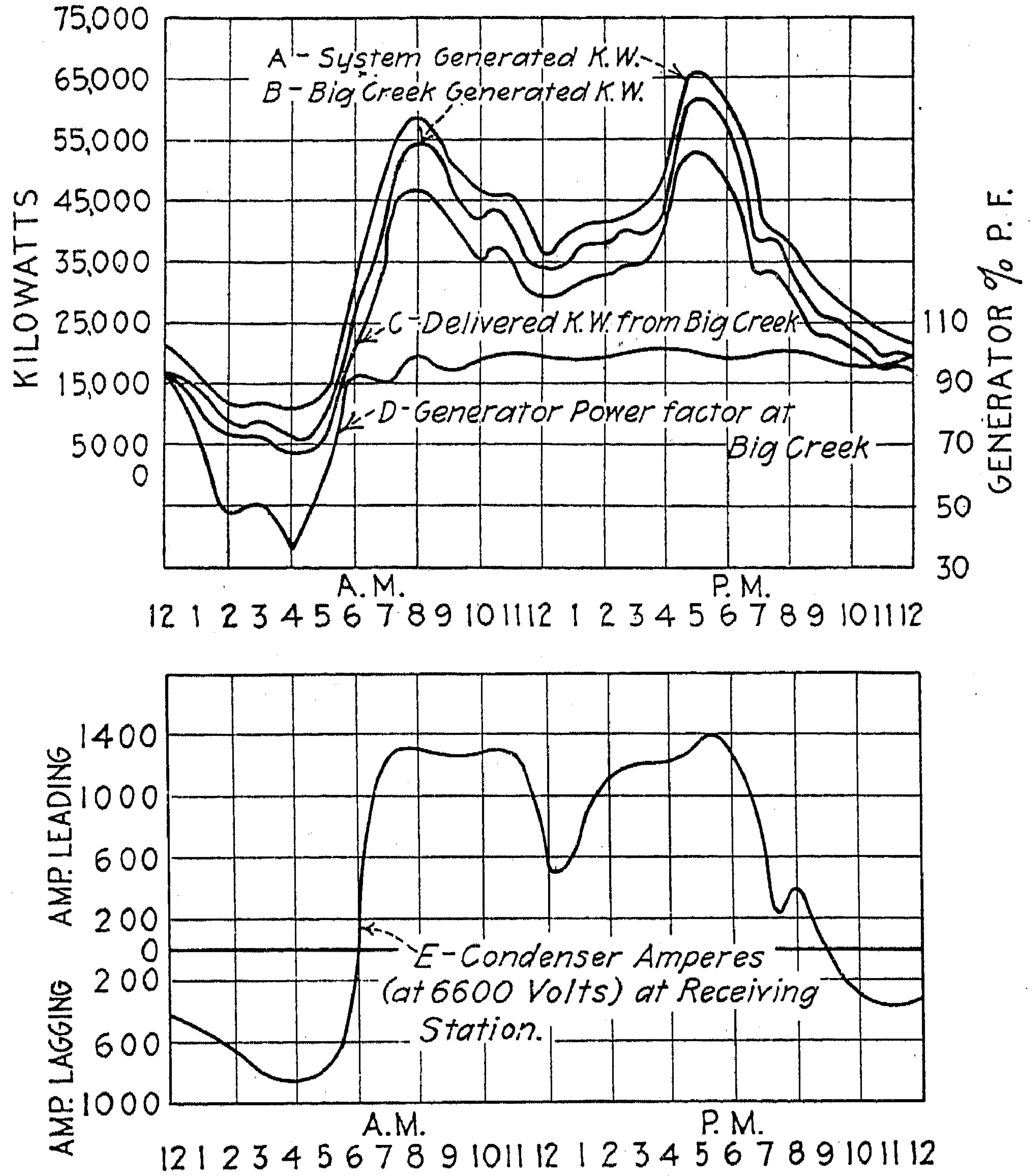


FIG. 3—TYPICAL DAILY OPERATING CURVES OF BIG CREEK SYSTEM, WITH ZERO LINE REGULATION.

Means had therefore to be furnished for using current in a reverse direction in the generator fields to counteract the excitation due to the leading current.

The curves of Fig. 3 show typical daily operating conditions as follows:

(A) System-generated kilowatts.
(B) Big Creek-generated kilowatts.
(C) Delivered kilowatts from Big Creek.
(D) Generator power factor at Big Creek.
(E) Condenser amperes (at 6600 volts) at receiving station.

The difference between A and B is on account of other generating stations being in operation on the system and being used to the limit of their capacity for correction of load power factors.

The speed regulation by the waterwheel governor has been excellent, so that no complications have arisen from this source.

As might be expected with a system of this magnitude, special consideration has been given to minimizing the effects of short circuits. Accordingly, the reactance of the generators of the two manufacturers has been made 70 per cent and 85 per cent respectively; of generating station transformers 5 per cent and 8.5 per cent; of receiving station transformers 5 per cent and 8.5 per cent. The result is that the instantaneous short-circuit current is only 330 per cent of full load on the generators and the sustained short-circuit current 110 per cent, with normal excitation, of full load. Under these conditions the waterwheel governors shut off water on short circuit before any serious change in speed can take place.

On account of the use of aluminum cable for the transmission line, it is very desirable to suppress an arc on the line before the wire can be seriously injured; and there is now under consideration the installation of a field-killing relay to be installed in the neutral of the generating station transformers, which will very quickly extinguish the arc and automatically permit the restoration of voltage immediately.

Of the short circuits which have occurred, none have been sufficiently serious to burn down the cable. Some of the outer strands have been scorched, but not sufficiently so to diminish strength. The scorched sections are of course removed at the earliest opportunity.

The causes of the short circuits, which have occurred, may be stated as follows:

1. In the rush of construction, a tree was left standing too close to the line and blew against it. The cable was scorched, but not seriously hurt. This occurred during the tryout period, and while the voltage was returned to normal in a fraction of a minute, the load was transferred to the steam plant, for some

time, while experimenting was done to endeavor to locate the trouble.

2. An irrigator tried to clean out a well near the line with a heavy charge of dynamite, blowing a lot of mud and water into the line. The current arced to the ground cable, but did not seriously injure the transmission cable.

3. One of the insulators on a disconnecting switch in one of the stations flashed over.

4. Seven other line short circuits have occurrred, five of which have been found to be due to flash-over of insulators, one to be due to an arc from line to a tree during high wind, and the location and cause of the other has not been discovered. In every case of the above, trouble was cleared by reducing the voltage at generators upon current being observed in the ground ammeters, after which service was immediately resumed.

In all cases of insulator flash-overs, the damage to insulators was so slight that service could be resumed, without repairs, immediately on extinguishing the arc. In two cases, two disks out of the string of nine were broken down or badly shattered. In the third case, two of the disks were slightly chipped on the edge.

In the remaining two cases the arcing bars with which the insulator hardware is furnished (see Fig. 4), protected the insulators against any damage. It is found that a flash-over will sometimes burn from one to two inches off the end of the arcing bar, and apparently does not go to the cable unless the direction and strength of the wind are such as to carry the arc out along the cable. The separation of the arcing bars is 51 in. (129.5 cm.), equivalent to a break-down potential of over 500,000 volts at normal frequency.

5. The most serious line interruption was caused by a mechanical defect in a dead-end clamp at the end of a 2700-ft. (823-m.) span across a wide and deep river. The weight and tension of the cable make a repair of this kind a serious matter. The clamp which failed was one out of 5000, so the percentage is not high.

Various features of the system have been described in detail in different technical journals and do not need repetition, but, for convenience, appendixes follow, showing how the growth of the Pacific Light and Power Corporation system made an installation of the magnitude of Big Creek an economic possibility, and giving the principal physical data of the development. The author desires to thank Mr. H. A. Barre and Professor R. W. Sorensen for their generous assistance in the preparation of this paper.

APPENDIX I

HISTORICAL

In 1897 the San Gabriel Electric Co. built at Azusa a hydroelectric plant consisting of four 300-kw. generators, which received their energy from a small stream with a 400-ft. (122-m.) head. The water power converted into electric energy by these generators at a potential of 500 volts was transformed to a potential of 15,000 volts and transmitted at this potential a distance of 25 miles (40 km.) to Los Angeles. Later, four other small hydroelectric plants varying in size from 150 kw. to 1500 kw. were added, and a "standby" steam plant of 2000 kw. was constructed, giving a total capacity of 6000 kw., 4000 kw. of which was water power.

January 1, 1905, the Kern River plant, a hydroelectric plant made up of five 2000-kw. generators, which transmitted its energy over 125 miles (201 km.) of line at a potential of 60,000 volts, was developed, and two years later, the original Redondo steam plant, which at that time made such a record for efficiency, was completed and its 15,000 kw. contributed to the service of the community. Even this, however, was not sufficient, for in 1911 it was found necessary to add to Redondo two 12,000-kw. turbine units, thus bringing up the available capacity of the system to 55,000 kw.

Even this tremendous supply of power rapidly became insufficient to meet the demand, and the company prepared to carry out the development of the now famous Big Creek project, which was to convert the energy available in Big Creek into electric energy and transmit it 240 miles (386 km.) to Los Angeles.

To transmit electric energy over such a distance with economy requires, of course, the highest practical potential, which in this case was selected as 150,000 volts, and plans for transmission at this voltage were drawn. These plans called for the immediate development of 60,000 kw. maximum, delivered at this voltage to the Los Angeles receiving station known as Eagle Rock substation.

This energy is generated by four 17,500-kv-a., 6600-volt generators, two in each power house. At Power House No. 1 the water is delivered to the wheels under an average head of 2050 ft. (624.8 m.) from a reservoir about five miles (8 km.) long and one mile (1.6 km.) wide, with sufficient storage capacity to operate the plant at full load about four months, which is equivalent to six or eight months of operation based upon a 60,000-kw. peak on the two plants. After leaving Power House No. 1 the water enters a second tunnel, whence it is carried 4½ miles (7.2 km.) to Power House No. 2, where it is delivered at an average head of 1857 ft. (565 m.).

PROJECTED DEVELOPMENT

Each of the two present power houses is so designed that its capacity may be doubled, simply by raising the height of the storage dam and installing the necessary generators, waterwheels, transformers and switching equipment. Future plans contemplate the erection of two other power houses, each as large as No. 1 and No. 2 will be when completed, at a lower elevation. These will operate under a somewhat lower head than power houses No. 1 and No. 2, but the difference in head will be supplemented by the addition of more water.

CONSTRUCTION

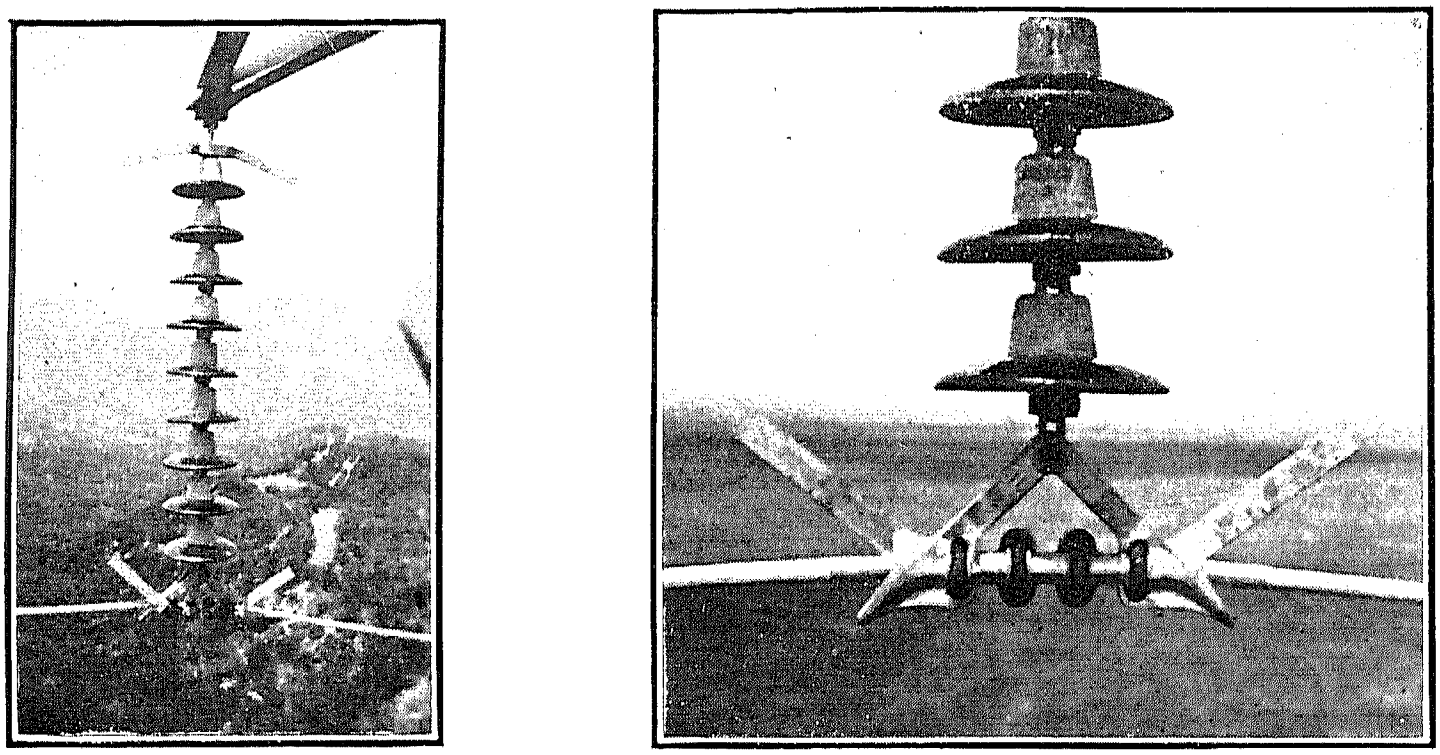
In order to take up the construction of the Big Creek project, it was necessary to construct 56 miles of standard-gage railroad over a very mountainous country, where even with the many curves the average grade is over 4 per cent. Materials were hauled over this track to the power house sites with shay locomotives, very often three engines being applied to a four-car train of heavy machinery.

It was also necessary to build two inclined railways, one to transport material from the end of the railway to the reservoir site and one to let material down to power house No. 2 from the railroad. When the work was at a maximum of activity 3500 men were employed, all of whom were housed in fifteen camps located in the mountains a long distance from supplies.

APPENDIX II

EQUIPMENT DATA

Two power plants, total capacity 64,000 kw.
Four 17,500-kv-a. generators.
Eight tangential waterwheels, each pair develops 16,000 kw.



[WOODBURY]

FIG. 4—150,000-VOLT SUSPENSION INSULATOR, SHOWING ARCING RODS.

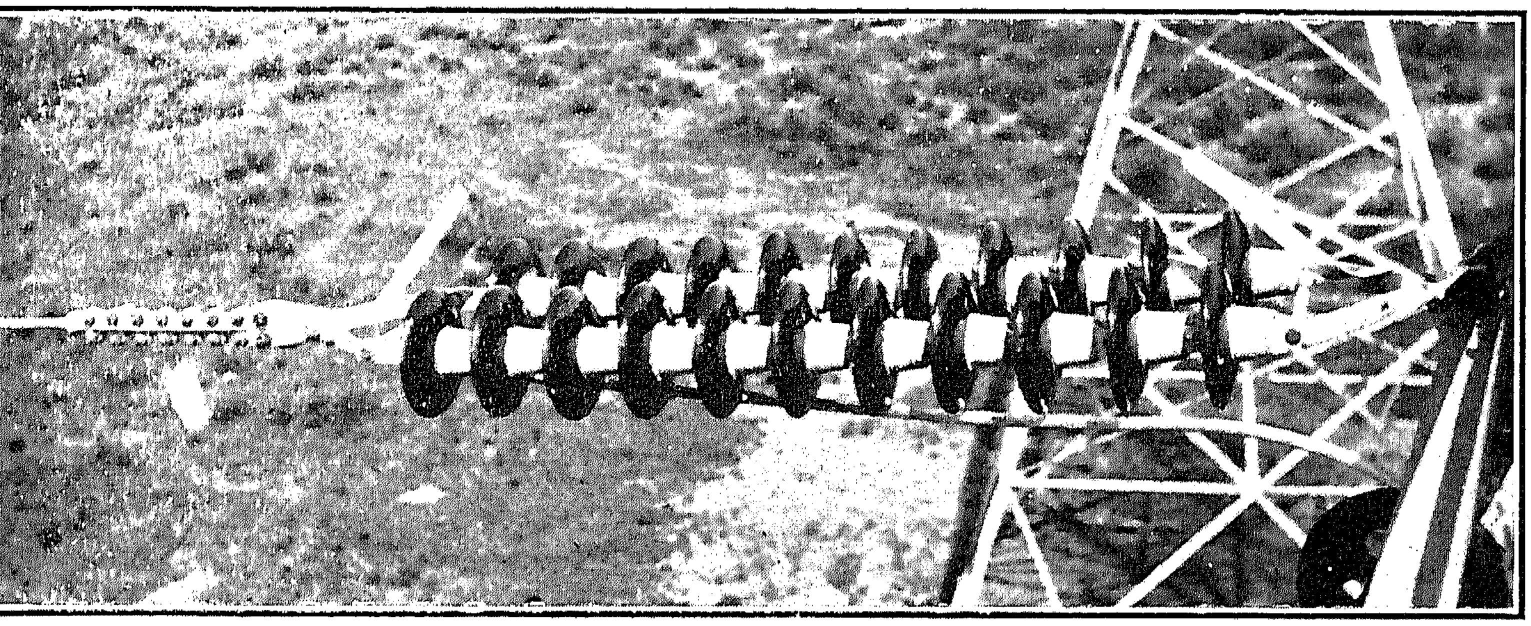
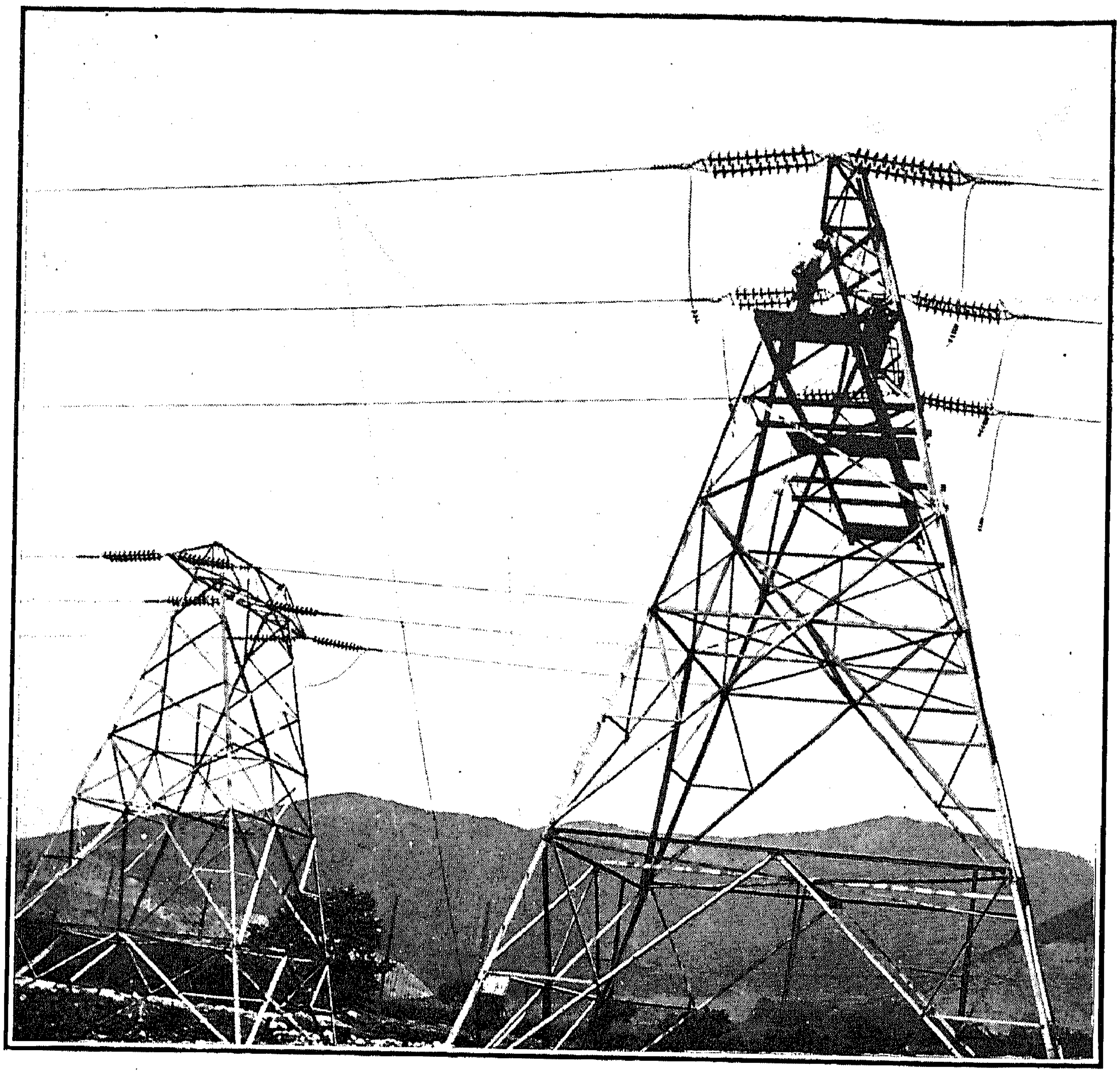
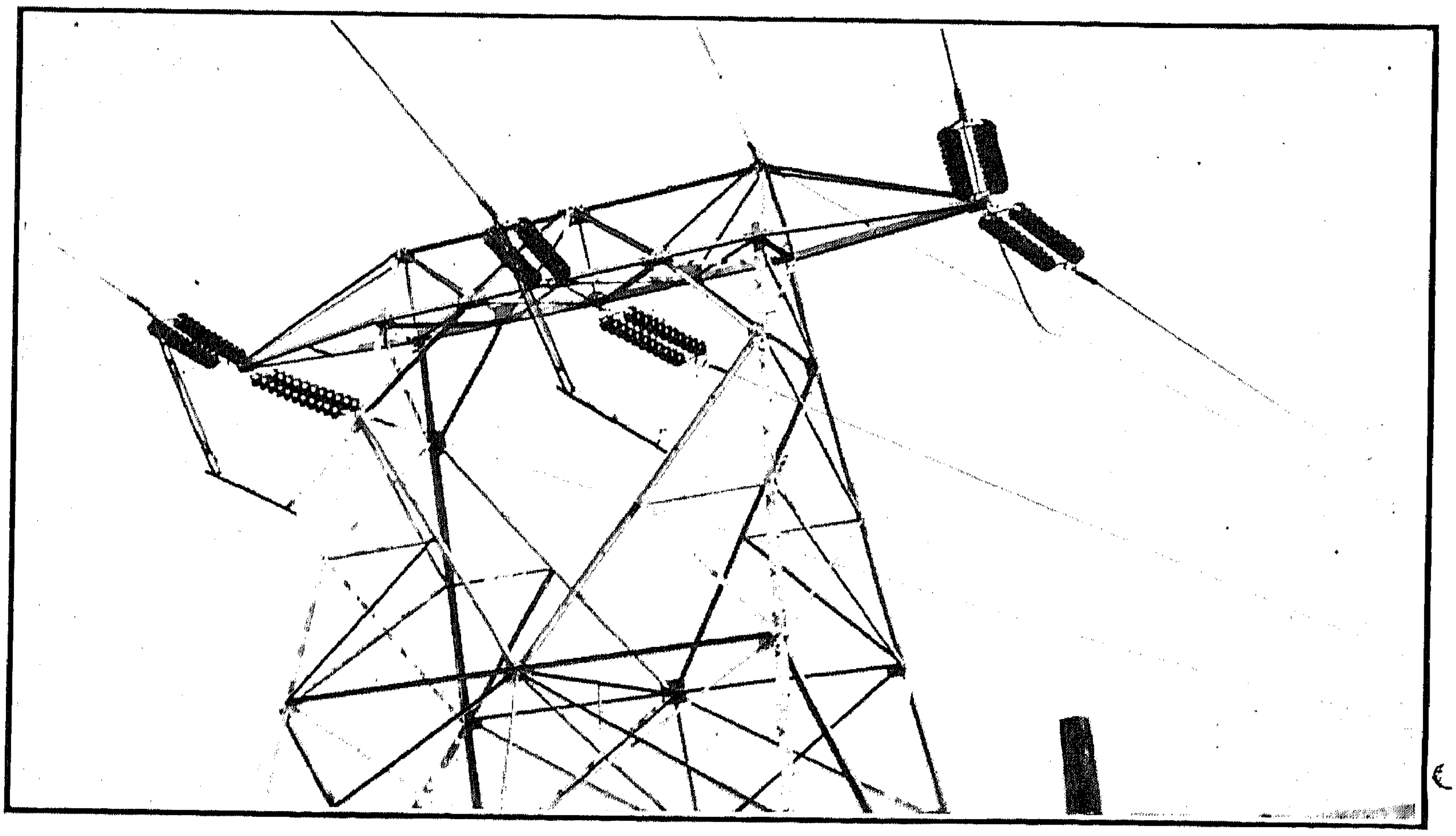


FIG. 5—150,000-VOLT STRAIN INSULATOR. [WOODBURY]



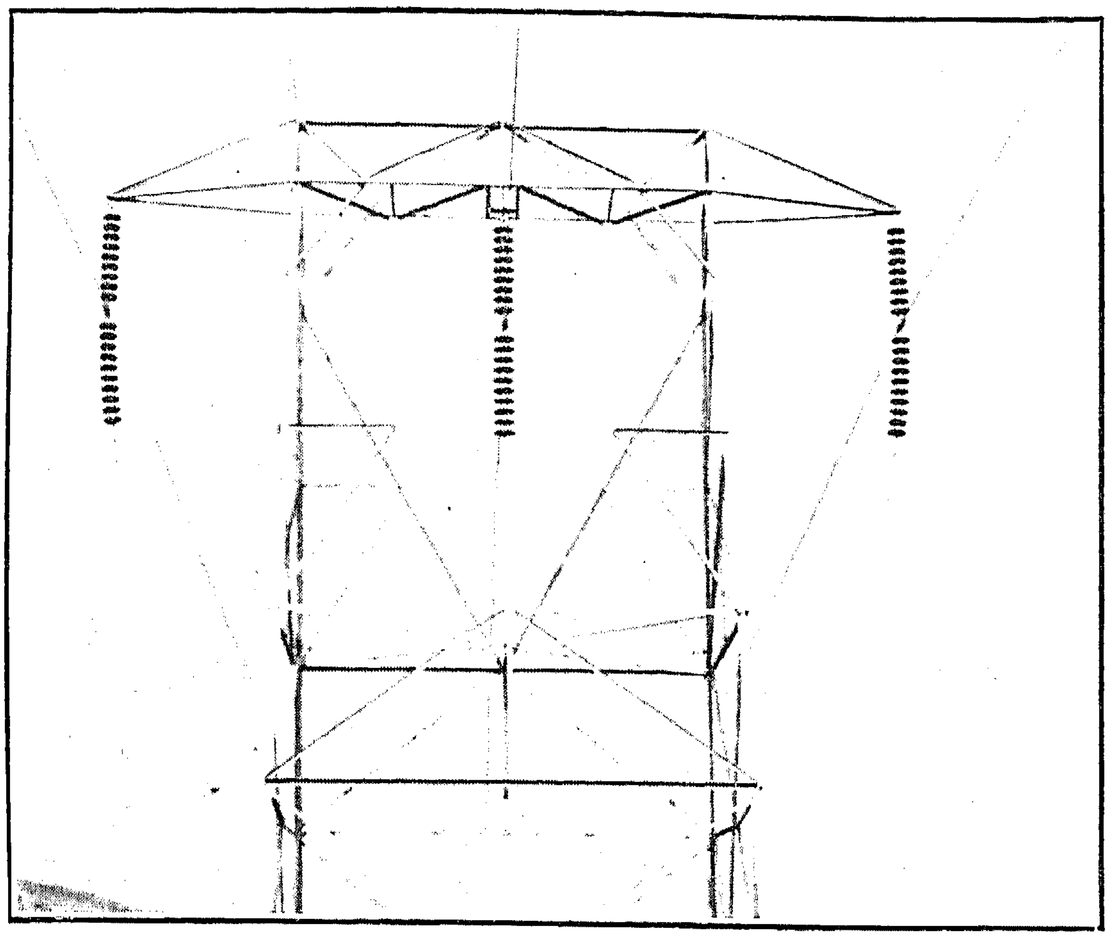
[WOODBURY]

FIG. 6—TYPICAL DEAD-END TOWER USED FOR LINE SECTIONALIZING BY OPENING JUMPER LOOP.



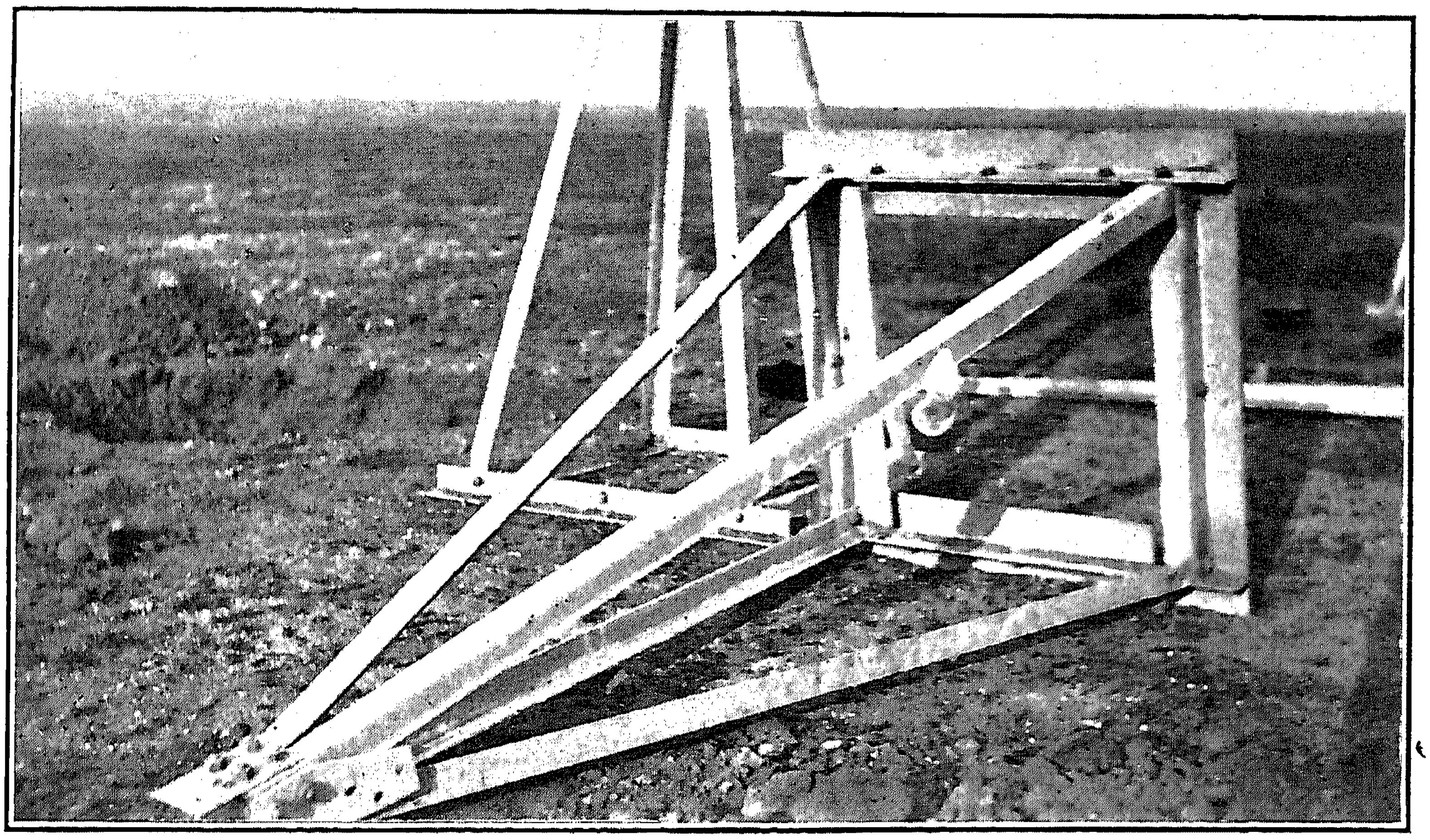
[WOODBURY]

FIG. 7—ANGLE TOWER, SHOWING BRACKET TO PREVENT LOOP FROM SWINGING.



[WOODBURY]

FIG. 8—METHOD OF TYING DOWN CONDUCTORS TO PREVENT UPLIFT IN COLD WEATHER.



[WOODBURY]

FIG. 9—STEEL FOOTING FOR STANDARD TOWER.

generator, full load, 24 hours, uses 240 acre-feet of water.

mum head of water, plant No. 1, 2100 ft. static. Plant No. 2, 1900 ft.

rvoir capacity, initial development, 51,600 acre-ft. Cubic yards con-te in dams, initial development, 120,000.

rvoir will operate plants 220 days on 50 per cent load factor.

nage area 88 square miles.

miles of 12-ft. tunnels through solid rock.

e-phase transformers, largest yet built, weigh 81 tons and contain ,000 gal. of oil.

er station transformers connected delta 6600 volts, Y 150,000 volts, th grounded neutral.

iving station transformers connected delta 150,000 volts, delta ,000 volts and 18,000 volts respectively.

15,000-kv-a. synchronous condensers at receiver end each require ,000 kv-a. to start.

er no-load conditions, 137,000 volts at generator rises to 150,000 lts at receiver.

rging current is 90 amperes at 137,000 volts, equals 21,500 kv.-a.

y amperes reversed excitation necessary to bring generator " down on ne " to zero potential, no-load condition.

er factor of generators is high, being above 95 per cent the greater art of the day.

rent is unbalanced approximately 12 per cent under no-load conditions n account of the conductors being in horizontal plane.

ler normal load conditions, this 12 per cent is reduced to approxi-ately 2 per cent.

otential of 4200 volts is induced in a dead section of the duplicate line 00 miles in length, distant 82 ft. center to center.

e loss at full load is 9 1/2 per cent. In addition there is 5 per cent ss in transformers, auxiliaries, etc.

DATA ON BIG CREEK TRANSMISSION LINE

eral:

ength, 240.41 miles power house No. 1 to Eagle Rock substation, s 0.74 mile tap to power house No. 2, total 241.15 miles.

oltage, 150,000 volts, 50 cycles.

Number of tower lines, 2.

Number of circuits per tower line, 1.

Capacity of each circuit, 57,500 kw. at 0.85 power factor for 11 per t regulation, using two synchronous condensers.

ht of Way:

Width of right of way, 150 feet.

Separation of center lines of tower lines, 82 ft.

wers:

Normal spacing in valleys where no sleet occurs, 660 ft.

" " " " " sleet occurs, 550 ft.

Maximum span, 2871 ft. (Sunland), 2776 ft. (Kings River).

Maximum span on standard towers, 1822 ft.

Maximum angle on standard towers, 0 deg. 49 min. (Normal span no et 1 1/2 deg. plus wind). Insulators take 45 deg. position.

Maximum angle on anchor towers, 48 deg., designed for 60 deg.; 114 deg. 2 min. under special conditions at tower No. 1.

Total number of towers, both lines, 3388.

Average number of towers per mile, single line, 7.08

Classification	Standard	Anchor and Angle	Special
Weight above foundation.	4300	6450	4485
Weight of steel footings ..	1305	1605	1305
Total steel per tower.....	5605	8055	5790
Spread at base with line.	20 ft.	24 ft.	20 ft.
" " " across line	18 ft.	24 ft.	18 ft.
Height above ground to insulation support.. ..	43 ft.	37 ft.	43 ft.

Unit Stresses:

Tension = 20,000 lb. per sq. in.

Compression $= \frac{16,000}{2}$ lb. per sq. in.

$\frac{L}{R}$ for corner posts, 125.

$\frac{L}{R}$ for bracing, 175, except where a larger value is approved by the purchaser.

Minimum thickness of members, 3/16 in.

Unit stress in bolts:

Shear............15,000 lb. per sq. in.
Bearings.........30,000 lb. per sq. in.

Design Assumptions:

Standard Towers:

(1) Wind load, 22 ½ lb. per sq. ft. of exposed area, with or at right angles to the line; wind pressure simultaneously applied to both faces of tower, and

(2) A pull in the direction of the line of 4250 lb. at the points of support of two adjacent conductors pulling on the same side of the tower, and

(3) A vertical load of 1000 lb. at each conductor support where conductor is unbroken, and of 530 lb. at each ground wire support, and of 500 lb. if conductor is broken, and

(4) A wind load of 600 lb. at right angles to the line at each conductor support where conductor is unbroken, and of 300 lb. at right angles to the line at each conductor support where conductor is broken, and of 500 lb. at each ground wire support.

The above loads are simultaneously applied.

Ground wire support designed to withstand an unbalanced pull of 5000 lb. in the direction of the line.

Anchor and Angle Towers:

Anchor and angle towers are designed for each of the following groups of conditions, only one of which groups is to be taken at a time:

I. (1) A wind load of 22½ lb. per sq. ft. of exposed area, with or at right angles to the line; wind pressure applied simultaneously to both faces of tower, and

(2) A pull in the direction of the line of 8000 lb. at each of the three conductor supports, on either side of tower, and of 8000 lb. at each ground cable support, and

(3) A vertical load of 500 lb. at each of the three conductor supports and of 265 lb. at each ground cable support, and

(4) A wind load of 300 lb. at each of the three conductor supports, and of 250 lb. at each ground cable support.

II. (1) A wind load of 22½ lb. per sq. ft. of exposed area, with or at right angles to the line; wind pressure applied simultaneously to both faces of tower, and

(2) A pull at right angles to the line of 8000 lb. at each of the three conductor supports, and of 8000 lb. at each ground cable support, and

(3) A vertical load of 1000 lb. at each of the three conductor supports and of 530 lb. at each ground cable support, and

(4) A wind load of 600 lb. at each of the three conductor supports and of 500 lb. at each ground cable support.

Number of conductors supported by each tower, 3.

Arrangement, in same horizontal plane.

Number of lightning ground wires, one at first; space for two if needed.

Smallest size angle iron used, 1¾ by 1¾ by 3/16 in.

Conductor:

Material, aluminum with steel core; steel double-galvanized.

Composition Metals	No. strands	Cir. mils	Weight		Elastic limit square inch	Ultimate tensile strength sq. inch
			per mile	per foot		
Aluminum......	54	605,000	2940	....	13,000	26,000
Steel...........	7	78,500	1118	....	115,000	195,000
Total.........	61	683,500	4058	0.77		33,600

Total resistance 35 ohms per leg.

Maximum working tension allowed—13,000 lb. per sq. in. in aluminum.

Stringing tension at 80 deg. fahr.

Ice allowance.................3130
No ice allowance..............4740

Type of joints, McIntyre sleeve on steel inside of compression aluminum sleeve.

Ground clearance:

On right of way................25 ft. at 140 deg. fahr.
At crossings..................Legal, as required.

Ground Wires:
Number per tower, 1.
Size, $\frac{1}{2}$ in. 7-strand.
Material, Siemens-Martin steel.
Breaking tension, 13,000 to 15,000 lb.
Maximum working tension allowed, 6500 lb. sleet—2100 ft. span; 5500 lb. no sleet.

Insulators:
Number, 190,000; 58 per cent of which are on dead ends.
Type, 2565-P Locke.
Diameter, 10 in.

Dry flash-over voltage........	590,000 suspension 720,000 anchor.	9 disks
Wet flash-over voltage.	420,000 suspension 420,000 plus anchor	

Routine Tests:
First test per disk, electrical, flash-over voltage.
Second “ “ “ mechanical, flash-over voltage, 5000 lb., after first elec.
Third “ “ “ electrical, flash-over voltage 5 min. after mechanical.

Ultimate tensile strength, 10,500 lb.
Maximum working tensile loading allowed, 4250 lb.
No. of disks used per chain, straight line, 9
“ “ “ “ “ “ dead end, 2 x 11 = 22.

Two chains are used in parallel on all dead ends to divide mechanical load.

Distance center to center of insulator, $5\frac{3}{4}$ in.

Two telephone circuits on an independent pole line 300 miles long. Resistance per circuit 4000 ohms. Storage batteries used on transmitters, and power-driven machines for ringing.

Eleven patrol stations are necessary, each requiring an equipment of tools and material weighing 10 tons.

DISCUSSION ON "SOME OPERATING CONDITIONS OF THE 150,000-VOLT TRANSMISSION SYSTEM OF THE BIG CREEK DEVELOPMENT OF THE PACIFIC LIGHT & POWER CORPORATION," (WOODBURY), SPOKANE, WASH., SEPTEMBER 10, 1914.

J. Harisberger: There has been considerable discussion as to the necessity of synchronous condensers on this system. I would like to know what actual practise in the operation of the system has brought out; could the system be operated satisfactorily without the use of synchronous condensers?

Mr. Woodbury's paper states that under conditions of short circuit the waterwheel governors shut off water before any appreciable change of speed can take place. I had the impression that the contrary would take place, that the governors would open up the gates.

I would also like to know if there are any transpositions in either of the transmission lines?

J. B. Fisken: One thing that struck me in listening to Mr. Woodbury's paper was the apparent success of the preliminary work. If all the work that Mr. Woodbury has told us of, has developed only the troubles he describes since the line was constructed, I think he is entitled to congratulations. I am reminded of an experience we had here eleven years or so ago when we first put into commission the line from Spokane to the Coeur d'Alene mines at 45,000 volts; none of us ever had the experience of seeing a line in operation at 45,000 volts; we didn't know what was going to happen, and inquiries were made as to what we should look out for. We were advised that all we had to do was to patrol the line and if the patrolman heard any insulators making any noise it was a sign they were defective. The noise was described as like the noise of frying steak. We energized the line and every insulator in that line sounded like frying steak, but there was not a single case of trouble; that of course was a comparatively low voltage.

It occurs to me that it might be possible to improve the operating conditions by adjusting the voltage so that for the greater part of the day the synchronous condensers might be cut out. The load factor is high, and I would like Mr. Woodbury to tell us whether it would be a practical operating proposition to cut out the synchronous condensers say from about six o'clock in the morning until eight o'clock at night. Of course, the only advantage of that is that it is a little less for the substation attendants to look after.

Another point on which I would like to hear some discussion is the method of tying down the conductors to prevent uplift in cold weather. In the line described by Mr. Woodbury, they use two strings, one of which would be in tension in hot weather and the other in tension in cold weather. In our tower line, we have only one short tower line, we use two dead-end insulators for the same purpose, and it would be interesting if we could get discussion on that and try to formulate an idea as to which is the better one.

One other thing I would like Mr. Woodbury to tell us about; that is, whether they use any resistance or reactance in the ground connections or whether it is a dead ground.

A. A. Miller: I have one question I would like to ask Mr. Woodbury. He mentioned the fact that in the 100-mile section of transmission line an induced potential of 4200 volts exists to ground. How frequently is this 100-mile section grounded when repairs are being made, at one place or more than one place?

M. H. Gerry, Jr.: The achievement of operating a line at 150,000 volts is a most creditable one and indicates in a marked degree the great progress in electrical transmission made in the last twenty years. This is a comparatively short time for the development to take place from potentials around 2000 or 3000 volts up to 150,000 volts or even more. It was my good fortune to be connected with the transmission business during the early days, some seventeen or eighteen years ago. About that time we built a system in Montana and began operating at 50,000 volts. It was then impossible to get a manufacturer in this country to endorse that voltage or unqualifiedly guarantee the transforming apparatus. I remember that we made a compromise by arranging to drop to half voltage if anything serious happened. As a matter of fact, a good many things did happen, but nothing occurred to disprove the general principle that high voltage was desirable and essential for long-distance transmission of power. It is rather an interesting fact that high-voltage transmission was developed in the West; the reason being that it was essential to accomplish the results under the existing conditions, and for the further reason that Western engineers and Western men generally were free from prejudice and were accustomed to undertake problems and seek solutions without regard to what had been already accomplished, provided that there seemed to be no good reason why it could not be done. As I have already said, we constructed in that early day a transmission system between the Missouri River, near Helena, and Butte, a distance of about sixty-five miles, operating at 50,000 volts. This system transmitted a large amount of power and was a success from the start. A few years later the pressure was raised to 70,000 volts, and now in the same vicinity there are lines operating at 100,000 volts and transmitting power up to 150 miles. My experience with all these lines has been most satisfactory. The troubles were few and mainly of a mechanical nature. Of course it took several years to analyze the insulator problem and to determine the necessary conditions in that direction, but to-day there is practically no electrical trouble on transmission lines on the Montana systems. In our part of the country the transmission lines in places reach considerable altitudes, and I would be interested to know the maximum altitude reached on the lines described by Mr. Woodbury.

E. Woodbury. Five thousand feet.

M. H. Gerry, Jr.: In Montana the lines sometime reach altitudes around 7000 ft. In such high altitudes there is some evidence of loss at the highest voltages, but as it is local it does not affect the general result. Most of the transmission lines in Montana are of wooden pole construction up to about 70,000 volts; at higher pressures the lines are mainly on steel towers. A very large amount of power is handled in this section, the principal transmissions being from points near Helena and Great Falls to Butte and Anaconda. The principal load is in the form of induction motors but there are also a number of synchronous motors used for operating air compressors and direct-current motor-generator sets. Every conceivable kind of load is handled on the Montana system; power, railway, lighting and all kinds of industrial applications to which electrical current can be applied. All the lines and power plants are now in one great system and but little trouble is experienced with regulation or with interruptions of service.

V. H. Greisser: I would like to inquire of Mr. Woodbury whether any extended tests have been made regarding the distribution of potential on the separate units and across the string of units of the insulator, and in general what was found. Also whether any tests have been made regarding the question of what we might perhaps call aging of insulators.

E. Woodbury: Mr. Harisberger and Mr. Fisken and Mr. Fraser have all asked about the same questions, about whether or not the condensers were necessary. I think you will find in the first part of the paper it says that the inherent regulation of the line is from 10 per cent above to 20 per cent below power house potential. I think that the principal excuse for the condensers is the remarkable regulation that they afford us. With the condensers in the receiving station we hold the voltage exactly where it is wanted at all times of the day and night, without any reference to what the power house is doing. When we first started up, the telephone line was not complete and we operated for about thirty days without any telephone line, and we gave very good service. The two condensers are 15,000 kv-a. each, making 30,000 kv-a. of leading component, which is required a good part of the day. Now, that would have to be supplied elsewhere or else the power house voltage would have to be raised to about 175,000, which would be approaching the limits of corona loss.

The matter of using steam turbo-generators for condensers is quite feasible, as Mr. Fraser mentions, but with us we have the vertical type and of course it is out of the question to separate the generator from the turbine.

We are also informed that we should not run the turbines without having steam on them, so there is some expense to produce enough steam to keep them in operation even though they are carrying wattless current.

Mr. Fisken's question about not running the condensers from

6 a.m. to 8 p.m.—Now, that is the time we need them the most. This curve in Fig. 3 only shows the kilovolt-amperes of one condenser, because at that particular time the other condenser was shut down and turbines in the steam plant were supplying 15,000 kv-a. wattless component, so you can see that from about 7a.m. the condenser is up to almost 1300 amperes, which is 15,000 kv-a., and it runs right through with a drop at the noon hour; otherwise if we did not have the condensers the power house voltage would go up to 175,000 or so with the constant difficulties in regulation.

Mr. Miller's point about the line 100 miles or so long having 4200 volts induced potential—before we ground either end of that 100-mile section, we make a static voltmeter test to get the true potential, and find it 4200 volts, and when we ground the other end, it drops to about 500, and then we put another ground at this end. Also the linemen all have positive instructions to put their ground on before doing any work.

In regard to Mr. Greisser's question concerning the stress on the different units, we have never made any tests on that, but there were some made at the time the insulators were being manufactured when they were tested for flash-over, etc., and I don't know just what means they had of determining what the stresses were, but we got the report that the stresses were very uniformly divided, which does not seem to agree with some articles I have read and papers presented before the Institute. Of course, as to the aging of insulators, we have not been operating long enough to know about that, as we have been operating only about ten months. As to the mechanical stress, they will stand about 10,000 pounds and we use two strings in parallel, so that the stress is divided, about half of the stress is on each string, and normally there will only be about 5000 pounds altogether, only about 2500 on each string, but they will go as high as 8000 or 10,000 lb., so that would be 4000 or 5000 on each string. Long spans of course are strung the same as the short ones, all pulled up with the dynamometer to the same tension.

Presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Spokane, Wash., September 10, 1914.

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A DISTRIBUTION SYSTEM FOR POWER PURPOSES

BY F. D. NIMS

ABSTRACT OF PAPER

The paper describes the distribution system of the Western Canada Power Company, Limited, touching on the overhead and underground systems in general. It describes the advantages obtained by duplicating lines, both for eliminating outages and from a financial standpoint. Mention is made of the advantages obtained by using a steel-taped lead-armored cable placed directly in the ground, figures showing the exact cost of such an installation being given.

IN laying out a distribution system for power purposes primarily, instead of a lighting or combined power and lighting load, several differences are encountered which lead to a much simpler and less expensive system. It is my purpose to describe the system of the Western Canada Power Company, Ltd., of Vancouver, B.C., giving some of these points in detail.

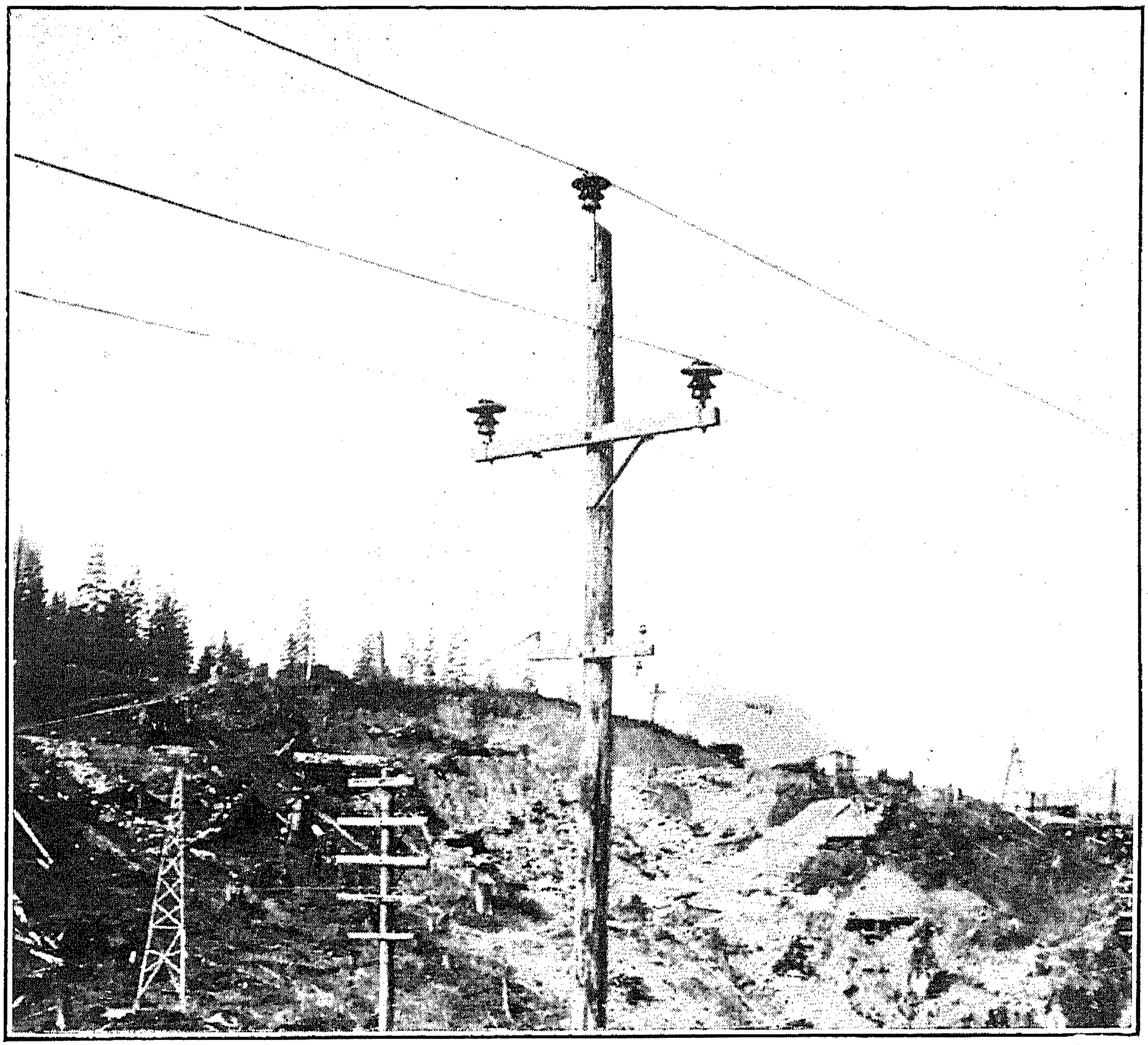
This company has its power house at Stave Falls, B.C., about 35 miles (56.3 km.) east of Vancouver, distributing power to Vancouver and the surrounding districts. The power house is located nearly in the center of a somewhat sparsely settled district containing several fairly large industries scattered throughout it at a maximum distance of 18 miles (28.9 km.) from the power house. A line leads south to the international boundary at Sumas, Wash., where it feeds a line of the Puget Sound Traction, Light and Power Company, of Bellingham, Wash., supplying 5000 kw. at 60,000 volts. This line is wood pole construction, single circuit, with pin type insulators, the conductor being a No. 0 equivalent steel core aluminum cable. The average span is 250 ft. (76.2 m.) and the maximum 970 ft. (295.6 m.) Arm pins are of the saddle type, made of one-in. (2.54-cm.) galvanized channel iron, no bolts going through the arm. The two legs of the pin are bolted together just above and below the arm. On angles, a small lag is screwed into the arm as a heel. This type of construction is shown in Fig. 1.

A steel-tower line, carrying two circuits of No. 0 hard-drawn stranded copper with hemp center, runs from the power house for 33 miles (53.1 km.) to the receiving station at Ardley, located half way between the cities of Vancouver and New Westminster, and practically at the center of gravity of the industrial load. At Ardley, power at 60,000 volts is delivered to the British Columbia Electric Railway Company, Limited, which takes the current into Vancouver, where it parallels with that company's own system. Ardley station also steps the voltage from 60,000 down to 12,000, at which it is distributed to Vancouver, New Westminster and the surrounding district. The standard steel tower is shown in Fig. 2. On account of difficulty encountered from sleet and snow during the winter of 1912–13, the middle arm was extended, and Fig. 3 is a view of the same tower as it stands today.

All 12,000-volt lines are on wooden pole construction and carry, as far as possible, only one circuit to the pole, it being our belief that better service can be provided through making each circuit loop back to the transforming station by an entirely different route than to duplicate circuits on a single pole line; where more than one circuit is on a pole line they are generally considered and operated as a single unit. This method, by proper sectionalizing of the lines, reduces the chance of outage to a minimum, and when work is being done on the line, or stumps are being blasted, a short section can be isolated and killed so that linemen are absolutely protected from adjacent circuits; or if a piece of stump is blown into the line, no short circuit is occasioned which burns off the conductors.

Aside from the power house and main receiving station, no substations are used, as there are no voltage regulators or similar apparatus which require attention. Transformers are generally placed on pole racks and operate as ordinary distribution transformers. Figs. 4 and 5 give a typical example of such a rack. It carries three 50-kw. transformers stepping from 12,000 to 2300 volts. Switches are either oil-break, pole type, or a combination fuse and disconnecting switch mounted on the pole. The company has designed and builds in its shop such a switch, which answers the purpose exceedingly well and costs very little.

Patrolmen are stationed at important switching points so that these switches may be operated quickly in case of emergency. Fig. 6 shows an installation of three 333-kw. 12,000- to 2300-volt water-cooled transformers in the outskirts of the city of Vancouver. These transformers are indoor type so that



[NIMS]

FIG. 1—POLE ON BELLINGHAM 60,000-VOLT LINE, SHOWING SADDLE TYPE ARM PIN

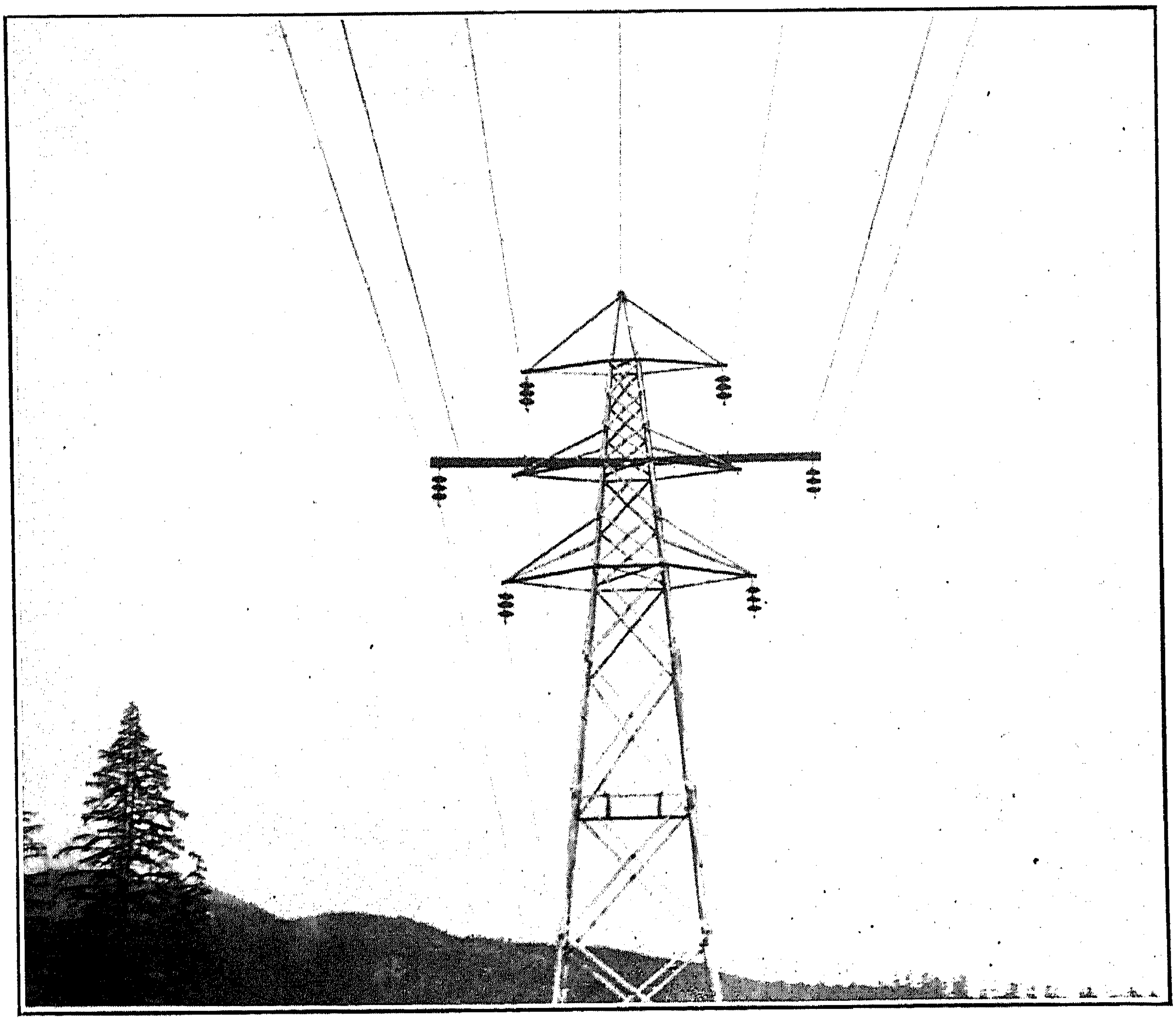


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FIG. 3—STANDARD STEEL TOWER WITH CENTER ARM EXTENDED

PLATE XC.
A. I. E. E.
VOL. XXXIII, 1914

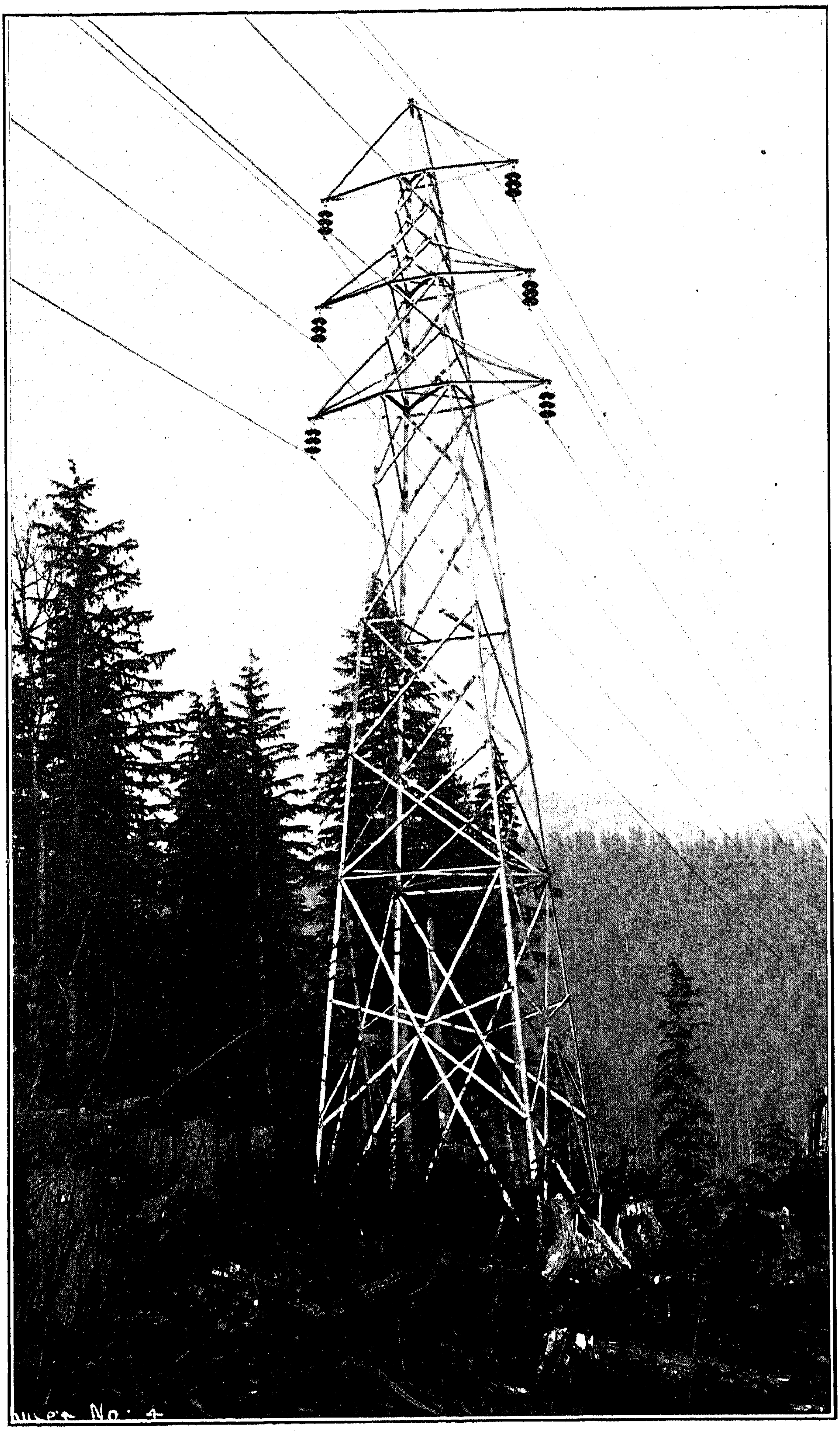

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FIG. 2—STANDARD STEEL TOWER WITH GROUND WIRE ON APEX

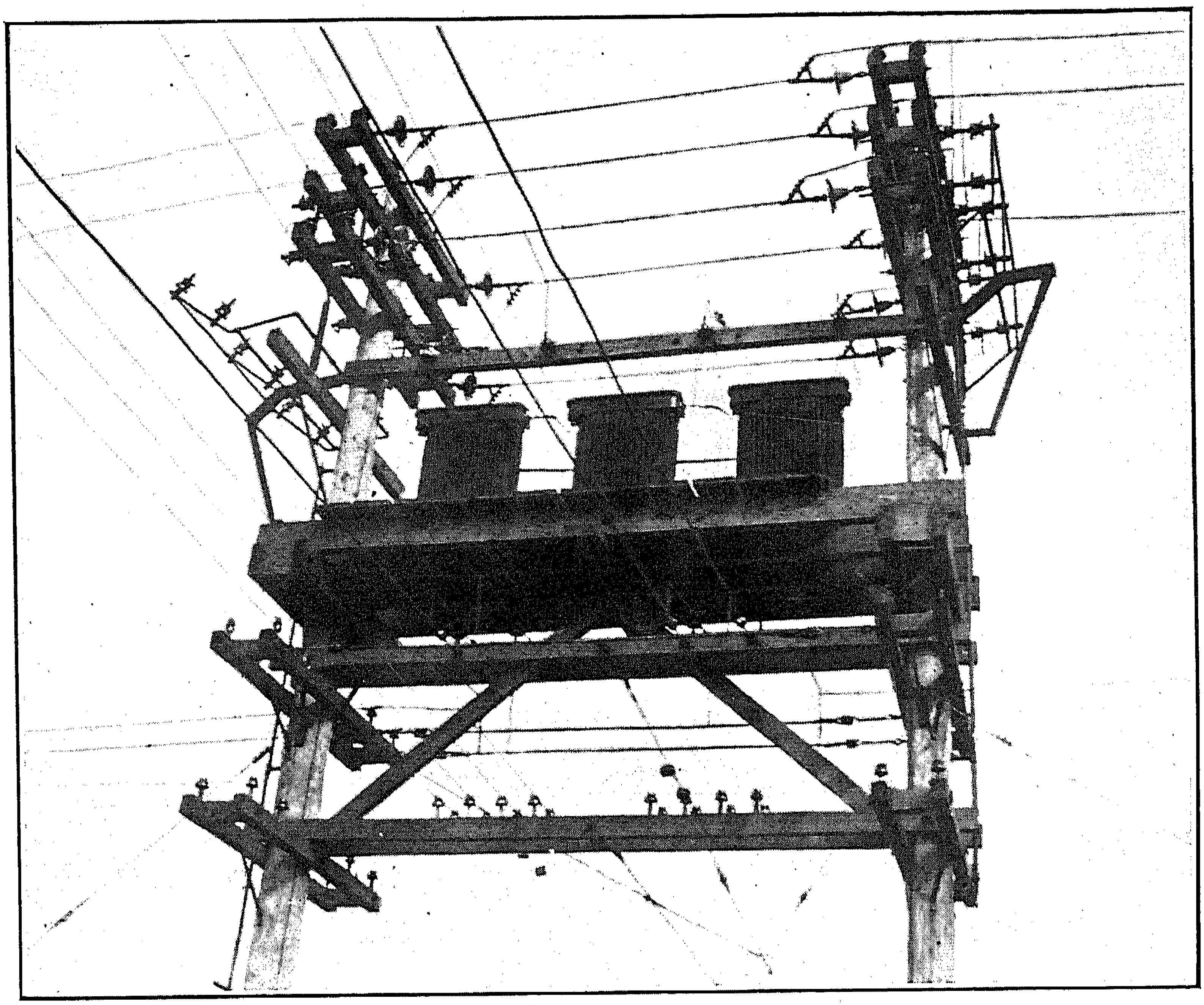

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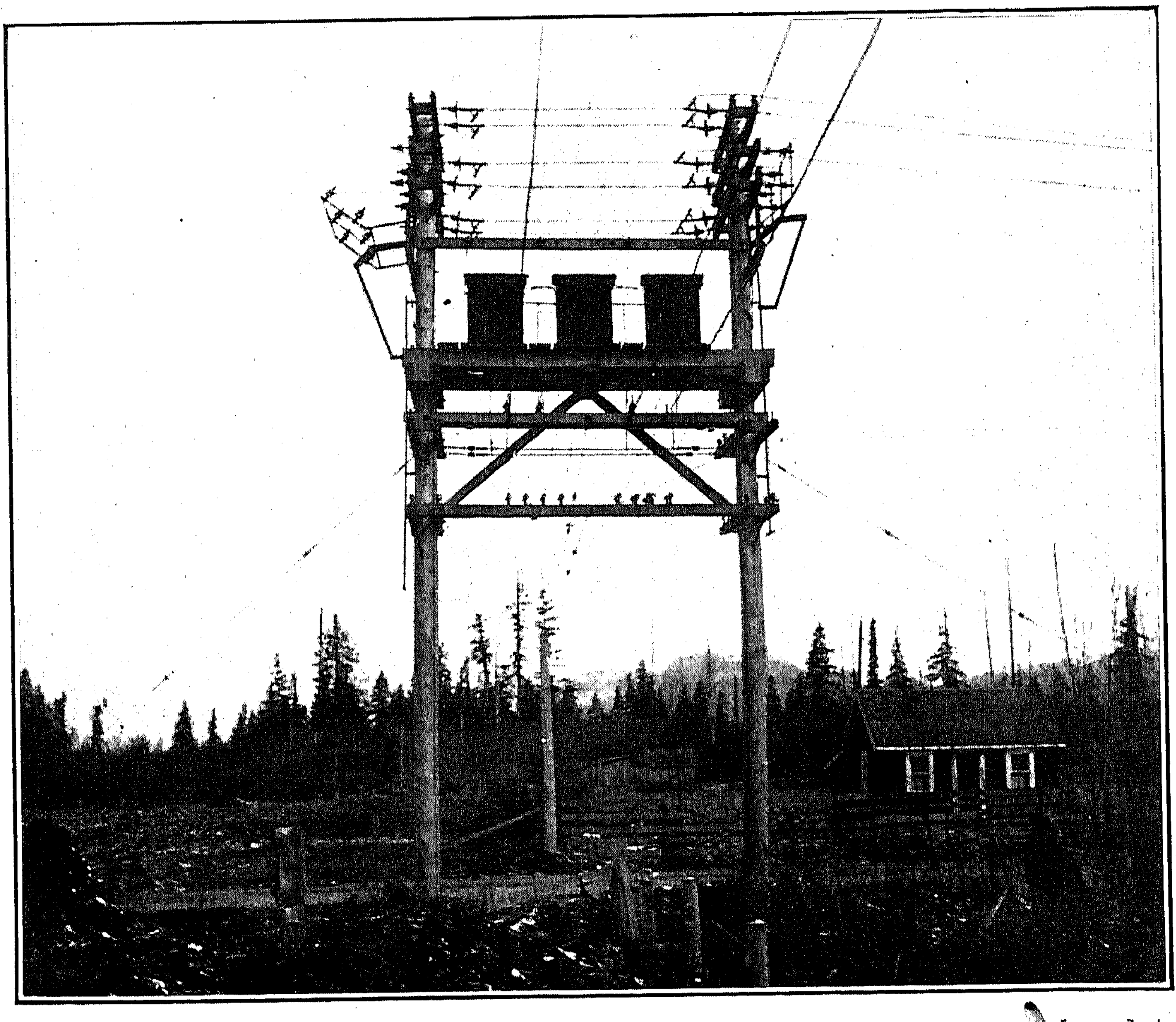
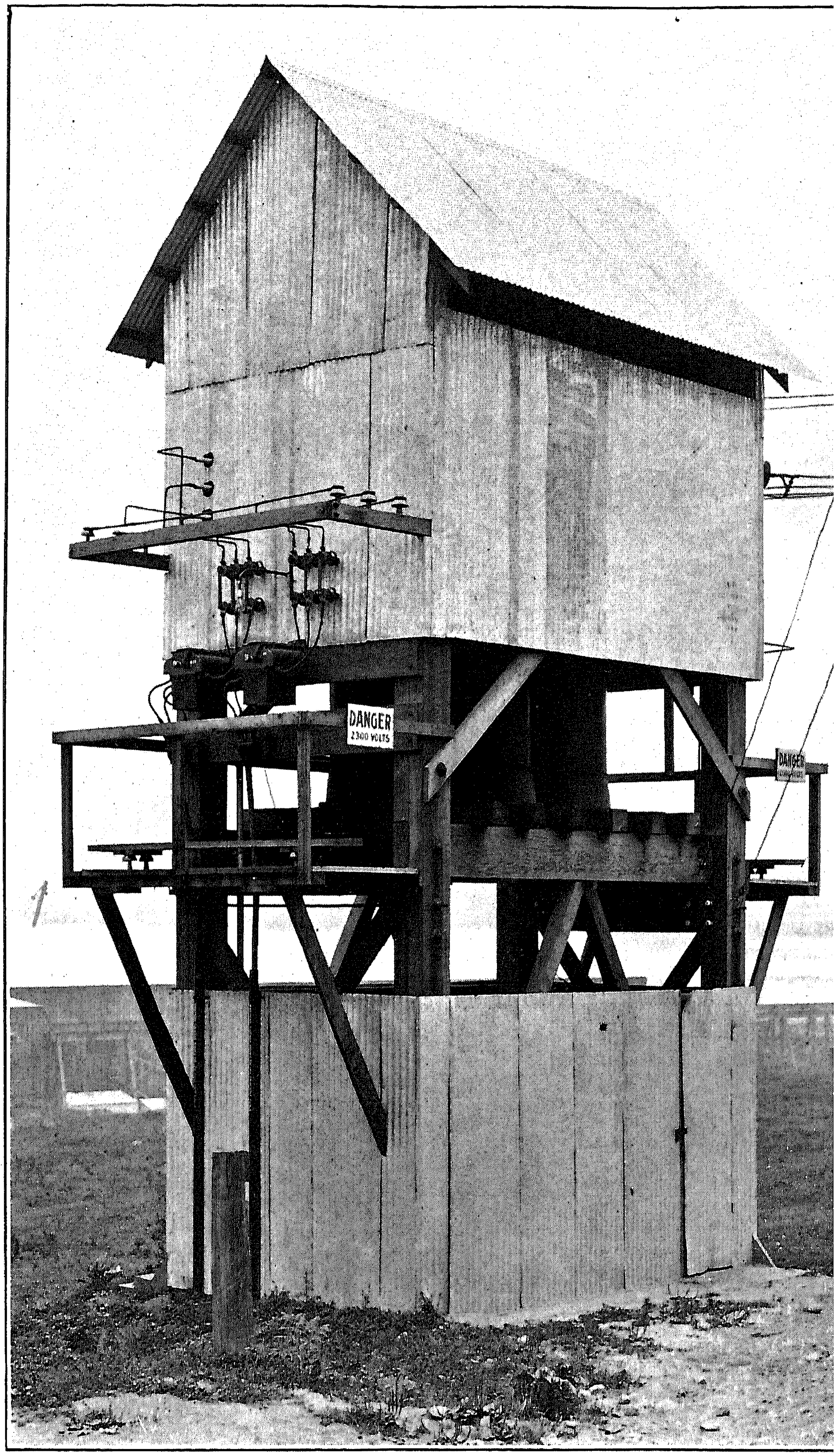
FIG. 4—OPEN AIR RACK CARRYING THREE 50-KW. TRANSFORMERS, 12,000—2300 VOLTS. OPERATED WITH POLE-TOP SWITCHES



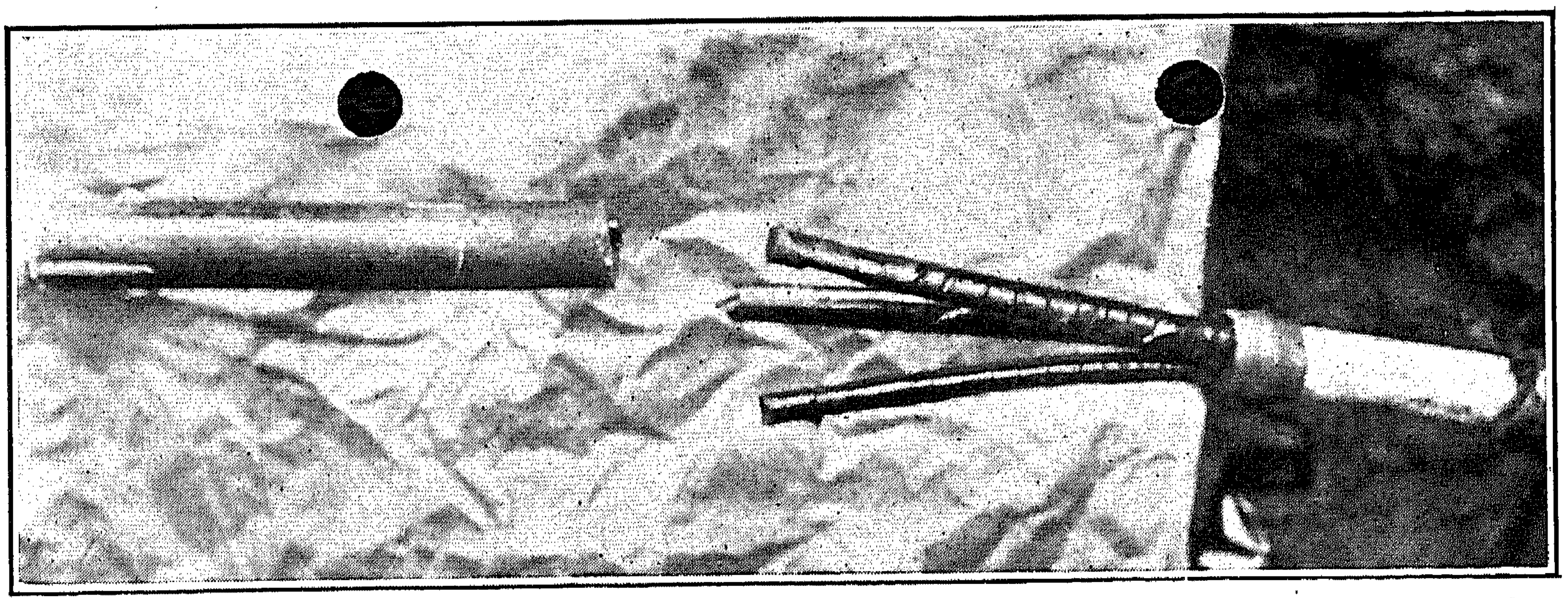
[NIMS]

FIG. 5—ANOTHER VIEW OF SAME RACK



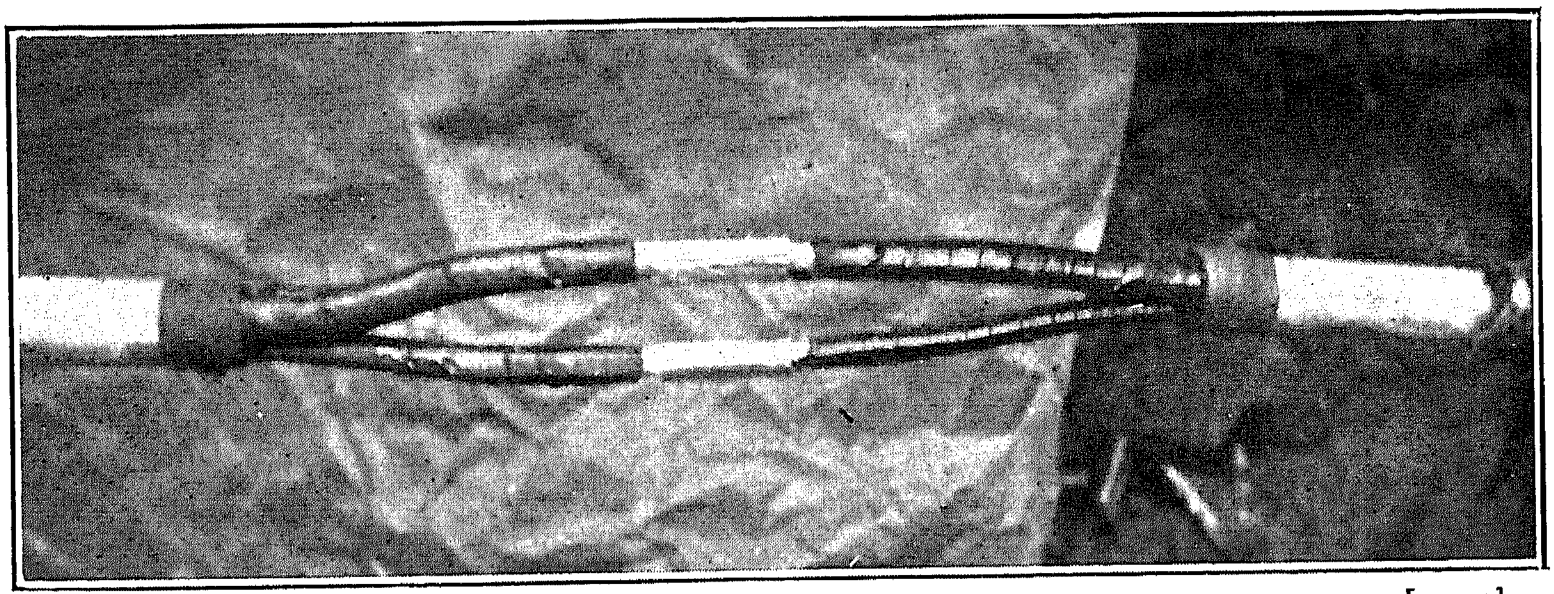
[N

FIG. 6—RACK CARRYING THREE 333-KW., 12,000—2300-VOLT WA
COOLED INDOOR TYPE TRANSFORMERS



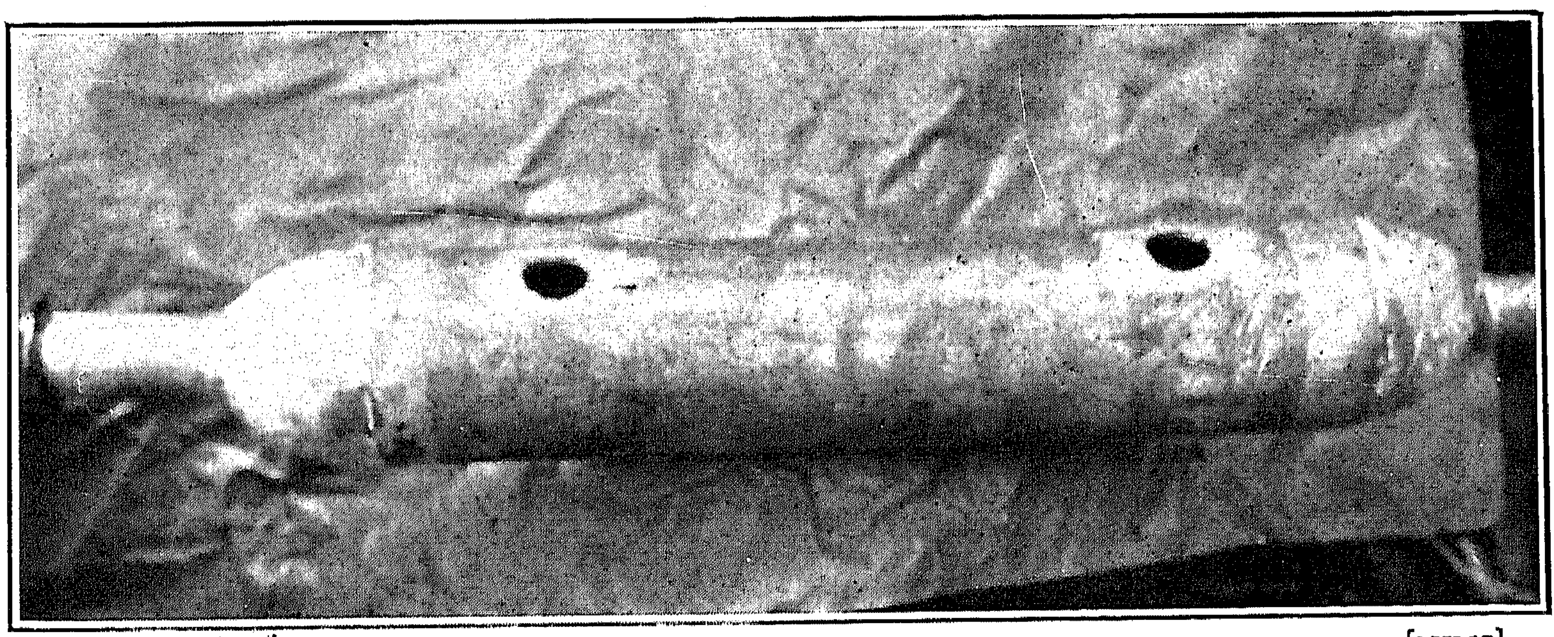
[NIMS]

FIG. 7—CABLES SHOWING ONE END READY FOR JOINT



[NIMS]

FIG. 7A—JOINTS WITH CONNECTORS SOLDERED



[NIMS]

FIG. 7B—JOINT WITH ONE END WIPED TO LEAD SHEATH OF CABLE

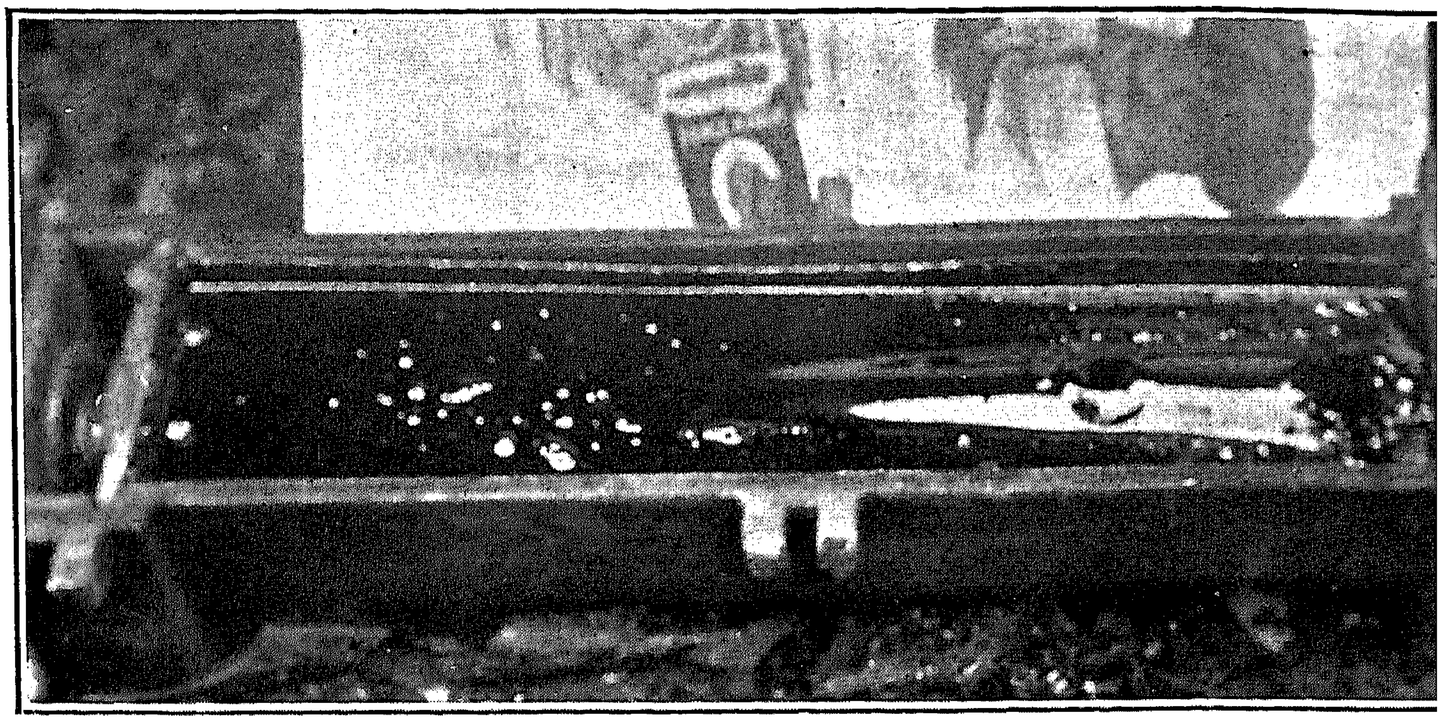


FIG. 7C—STRAIGHT JOINT BOX, PARTLY FILLED WITH BITUMEN, FOR COVER

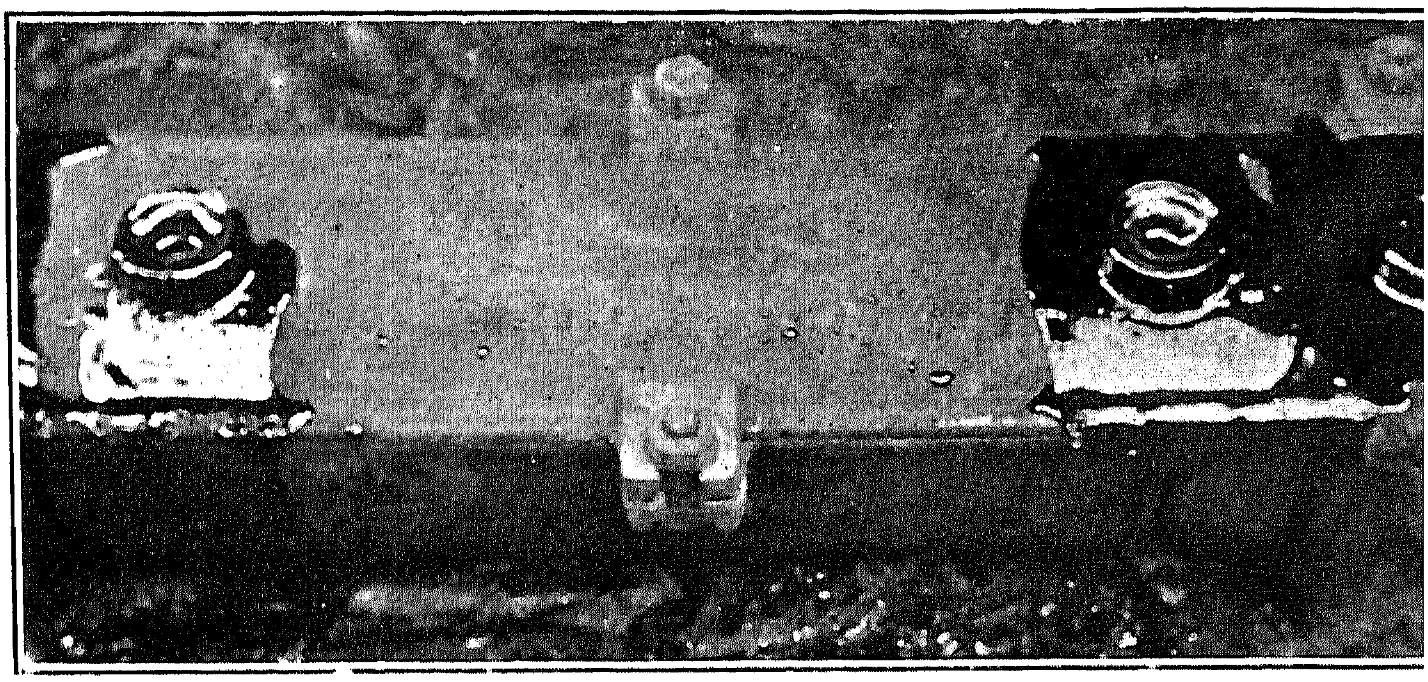


FIG. 7D—JOINT COMPLETED

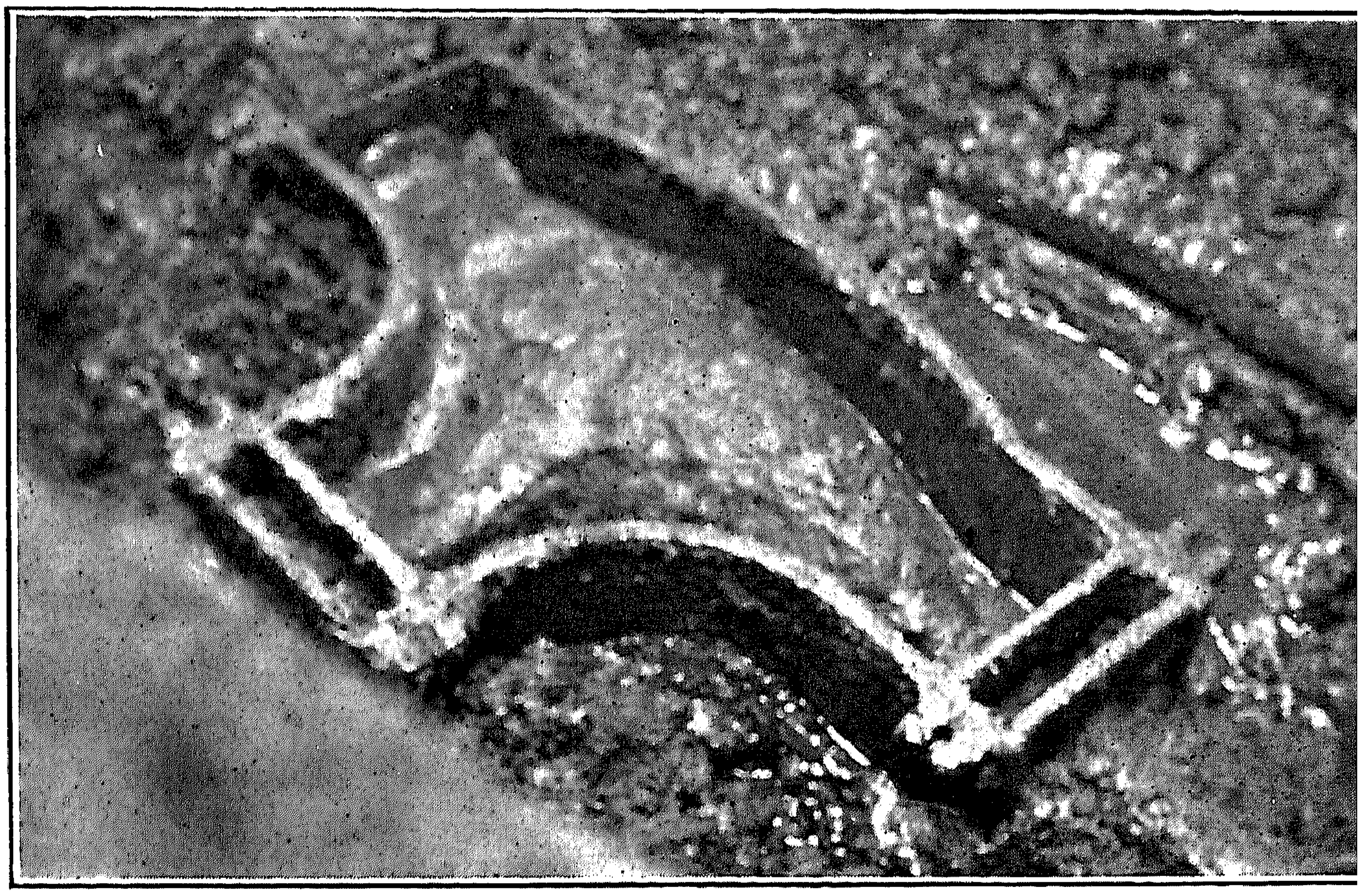
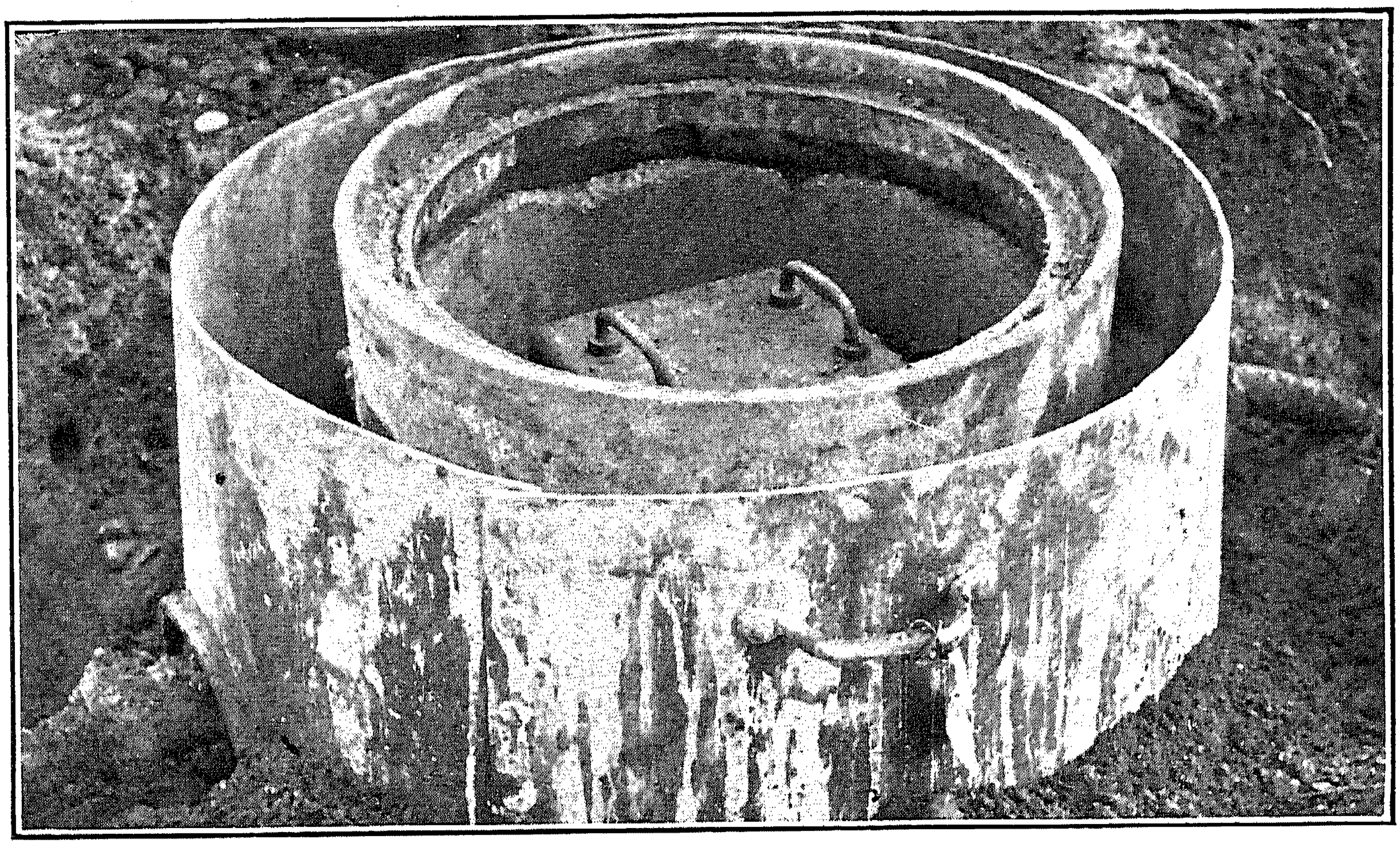
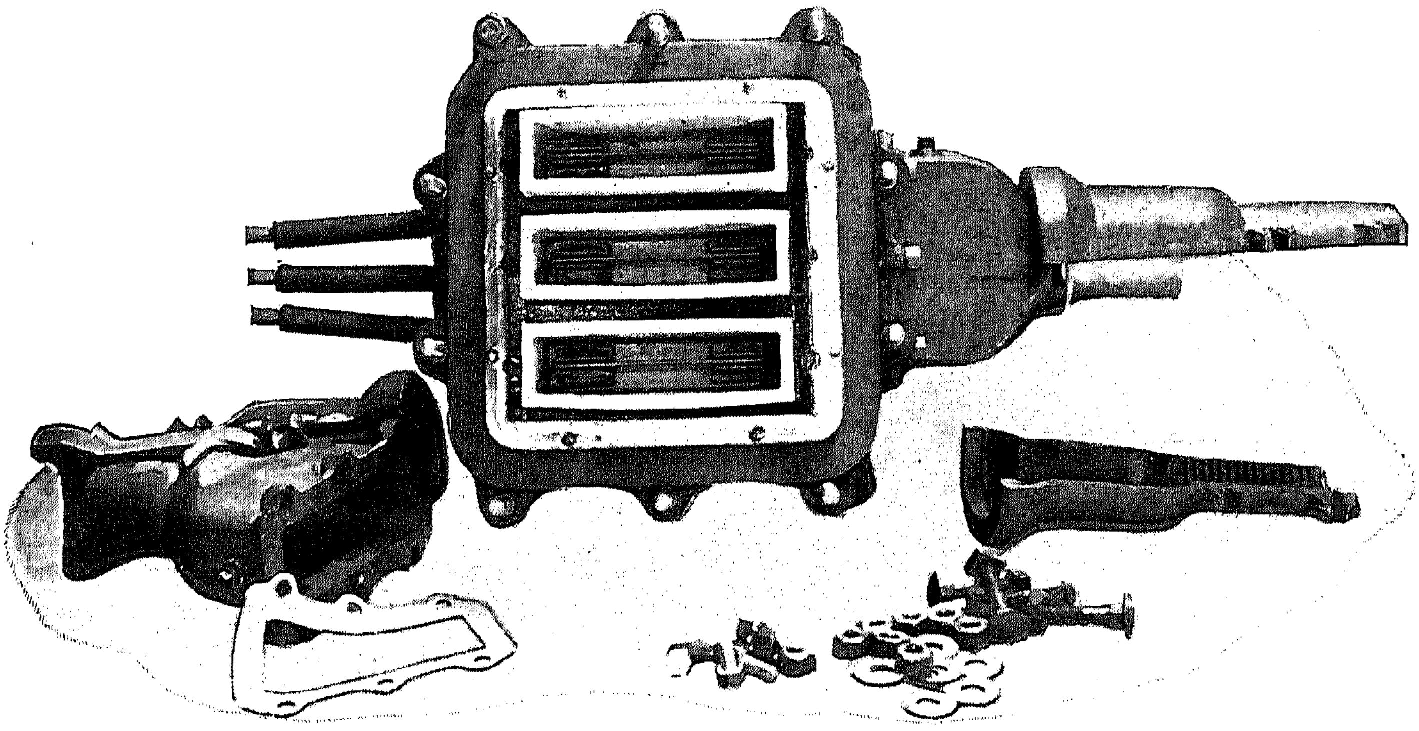


FIG. 8—TEE JOINT HALF FULL OF BITUMEN



[NIMS]

FIG. 9—SECTION BOX IN PLACE AND OUTER FORM READY FOR POURING CONCRETE



[NIMS]

FIG. 10—SECTION BOX SHOWING PORCELAIN COMPARTMENTS AND COPPER LINKS

it was necessary to roof them over with galvanized sheeting. Water for cooling is taken from the city mains. The view is from the 2300-volt side, showing the disconnecting switches, outdoor type oil switches, cable terminals and cables with their pipe protection. A patrolman, who lives in the vicinity, visits the station periodically and adjusts the flow of water through the cooling coils.

In some cases, where a mill or factory has sufficient electrical apparatus of its own to warrant the employment of a skilled electrician, water-cooled transformers are installed in a small galvanized iron building. In short, the entire 12,000-volt system is handled in the same manner as a 2300-volt system, except that a circuit must be killed for a man to work on it.

Distribution in the cities of Vancouver and New Westminster is at 2300 volts by means of steel-taped and lead-armored cables laid directly in the ground, without conduit or other protection, except where crossing railway tracks or busy streets, where wood duct is laid to facilitate the pulling out or replacing of a cable without interruption to traffic. A trench is dug 30 in. (76.2 cm.) in depth, and of a width corresponding to the number of cables to be laid, (cables in place are from 4 to 6 in.—10 to 15 cm.—apart) the cable is reeled out and dropped directly into the trench. Joints are made by joint boxes, which cover the same character of joint that is made in the ordinary lead-covered cable, the space between the lead and the box being filled with ordinary bitumen, the box serving as a protection to the lead and also clamping the steel armor on both sides of the joint, providing electrical conductivity in the steel as well as mechanical strength in the cable as a whole. Fig. 7 shows five views of making a straight joint; the first showing the cable with one end ready for the joint, the armor having been stripped back, the lead cut back and the conductors separated. Fig. 7A shows the joint as made with copper sleeve connectors. Fig. 7B shows the joint with one end wiped to the lead sheath of the cable. Specially refined bitumen is poured through the holes in the lead sleeve after the ends are wiped, and the holes then capped with lead. Fig. 7C shows the straight joint box, itself, with the cover off, half full of bitumen, and Fig. 7D the completed joint. Fig. 8 shows the lower half of the joint box in the trench. Taps are made in a similar manner by means of a three-way box. At frequent intervals section boxes are placed in the line, these boxes being 18 in. (45.6 cm.) below ground level in a small manhole, or, more properly, handhole.

These holes have, as a bottom, a pad of concrete on which the box rests, the walls being circular and of cast iron; the entire hole being 26 in. (65 cm.) in diameter. The walls are flanged to take an ordinary cast manhole plate, which is used as a covering, these being flush with the street. Fig. 9 is a section box and hand hole with the steel form around it ready for pouring concrete. After pouring, the form is slipped off and the earth tamped in up to the concrete. The box has a bolted top which can easily be removed, and the copper links, which are set in porcelain compartments, can be taken out by means of wooden tongs. These boxes are used to isolate sections of cable when necessary to make new taps or work on the live conductors in any way, and also as interconnecting links between various cables, giving as a result several rings or loops. Fig. 10 shows a view of one of these boxes before placing in the handhole. The bolted cover is removed, showing the porcelain compartments and the copper links. The bell is of brass with a lead sleeve wiped in which fits over the lead sheath of the cable and is then wiped to it. After the conductors are connected and the lead joint wiped the bell is filled with refined bitumen, through the plug holes left for that purpose. The split armor clamp is also shown on the right side of the box.

Distribution transformers are placed either in vaults on the customers' premises or on poles, in which case the cable is carried to the top of the pole, where it terminates in an outdoor type terminal. Secondaries may be carried either back down the pole in the same kind of cable or run overhead to the building. Where cables run up the poles an additional protection is given by means of an iron pipe through which the cable runs. This pipe extends to a point about ten feet above the ground.

The question of cost on such an underground system must be taken up in each individual case, for it will vary a great deal with the quality of soil, cost of labor, probabilities of taps, extensions, etc., but it may be said, in general, that in places where it is not required to lay more than four cables in a trench, the steel tape cable, laid directly in the ground, will be found to be cheaper than any of the other systems. As a typical example of actual costs the following gives an idea, the figures being taken from a job carried out in Vancouver during 1911-1912.

Size of Cable	Amount laid, feet	Cost per ft., cents	Total cost
No. 00	73,336.6	52.24 to 62.18	$44,319.26
2	560.0	42.5	238.00
6	1,071.3	29.6	317.10
TOTALS	74,964.9	60 cents average	$44,874.36

Pulling cable (including splicing straight joints) $0.04 per ft.				2,992.69
Trenching				
Unimproved streets	28,224.2 ft.	@ 0.50 cts. per lin. ft.	14,112.10	
Macadamized	13,207.9 "	@ 0.58 " " "	7,660.58	
Plank walk	1,190.2 "	@ 0.58 " " "	690.32	
Concrete walk	261.1 "	@ 0.95 " " "	248.04	
Wood block (con. base)	6,547.7 "	@ 0.95 " " "	6,220.32	
Brick Do.	203.0 "	@ 1.05 " " "	213.15	
Stone Do.	4,302.2 "	@ 1.10 " " "	4,732.42	
Bitulithic pavement	1,095.8 "	@ 1.15 " " "	1,260.17	
TOTALS	55,022.1	0.632 average		35,137.10
74 straight joint boxes		@ $14.90		1,102.60
15 Tees		@ 22.90		343.50
4 Outdoor terminals		@ 29.00		116.00
2 Inside terminals		@ 10.15		20.30
8 End bells				10.00
Labor on terminals & joints (Not st. joints)				409.04
6 railway crossings (matl. 140.22 Labor 94.86)				235.08
96 street crossings (matl. 2440.18 Labor 1437.25)				3,877.43
Additional excavation for changes in grade				439.49
Moving building material etc.				294.70
15 section boxes, labor and material				2,250.00
TOTAL COST				$92,102.29

Cost per ft. of cable $1.23
Cost per mile of cable $6483.84
Feet of cable per ft. of trench 1.36
No overhead charges or engineering are included in the above.

Operating troubles have been few and far between, there having been, during two years' operation, but three cases. Two of these were caused by city workmen making sewer excavations taking the cable for the root of a stump and chopping into it with an axe or pick. On one of the pieces of cable so damaged we found the marks of 13 blows before the axe cut through to the conductor. The third case was a faulty joint at a section box which broke down the day after it was placed in service.

A complete card system is kept containing records of all cable locations, joints, etc., and we installed our own hubs in the streets as markers, the city hubs not being well defined.

This cable is practically a submarine cable, and in fact we have one length of 1500 ft. (457 m.) crossing the Pitt River, which has now been in service for two years without any trouble. The bottom on which it lies is fine silt or sand and there is a four-mile current caused by the tide. In another case it was necessary to cross a railway yard to furnish power to a pump located about 1000 ft. (304 m.) from the factory of the consumer, the motor driving the pump to be controlled from the factory. As the expense of excavating for the laying of a cable would have been excessive and there was already a 12-in. (30.4-cm.) water main running from the pump to the factory, the cable was pulled in the pipe, the inlet and outlet of the cable being made through stuffing boxes. This has also proved very satisfactory.

The cable is composed of stranded conductors insulated with paper, the three conductors being insulated again with paper as a unit before the lead is put on. In most of the cable in this installation the conductors are sector-shaped, so that there are no spaces to be filled with jute or other material and a smaller over-all diameter is obtained, for a given size, than is possible with the round conductor, thus requiring less lead, steel and jute, and making a cable lighter in weight. The lead sheath is $\frac{1}{8}$ in. (3.1 mm.) thick and over this is wound jute yarn impregnated with tar. Outside of this jute are wound, in the same direction, two layers of mild steel tape 0.039 in. (1 mm.) in thickness and 1.5 in. (37 mm.) in width, so laid as to break joints. Over this tape is again wound yarn impregnated with tar. The over-all diameter of such a cable in three-core No. 00 for 4000 working voltage is about 1.75 in. (34.5 mm.).

One of the most important factors in the use of a cable buried directly in the ground, instead of being in conduit, is the ease with which heat can be radiated. Although the amount will vary somewhat with the character of the soil, it is safe to say that on this account an increase of approximately 15 per cent may be allowed in the current-carrying capacity over that in conduit. Exhaustive tests on this subject are now being carried out.

In regard to the life of a cable installation of this sort, nothing definite can be said as yet. The writer has personal knowledge of a large installation which has been in service in volcanic soil in the City of Mexico since 1900, and no perceptible deterioration has occurred, except where exposed to extreme electrolytic action, and in these cases it had a much longer life than lead cable in conduit in the same vicinity, due to the steel tape acting as a protection.

DISCUSSION ON "A DISTRIBUTION SYSTEM FOR POWER PURPOSES" (NIMS), SPOKANE, WASH., SEPTEMBER 10, 1914.

J. B. Fisken: It was my good fortune last year at the Pacific Coast Convention at Vancouver to see quite a good deal of the work that Mr. Nims had done with this ductless cable. I have noted some of the points on which I would like to hear some discussion. These are: the relative cost of ductless and duct lines, the use of the various insulations, such as paper, varnished cambric, and rubber, and the relative advantages of the wire of the shape he mentions as against round wire.

It appears to me that this system of ductless underground cable is eminently suitable for distribution in residential districts, but I don't see how it can be practicable in congested districts such as the business part of the various cities where you might have as many as thirty or forty cables in one duct line; it would appear to me that there would be many operating difficulties—or, rather, maintenance difficulties in keeping such a lay-out as that in commission.

P. M. Lincoln: This matter of the kind of cables that Mr. Nims is using is probably the most interesting point in the paper.

I ask first if he has any difficulty in locating faults and if he can locate them so that he does not have to dig very much when he comes to find the fault and repair it; also I presume that this type of installation would not be at all applicable where you have to take up pavement to make repairs—in that case I presume it would be out of the question.

The question which Mr. Nims mentioned, of this being much more capable of getting rid of heat, is an important one. When the Niagara Falls plant was installed 2200 volts was the voltage and it was considered high at that time—1893-4;—those were 3740-kv-a. generators, and there were ten of them, which gave a whole lot of current to take care of. That current was distributed to our various customers at 2200 volts and it was distributed through cables in ducts, and the problem of getting rid of the heat in those ducts was at that time and still is one of the most difficult problems which has to be dealt with. I can assure you that any means of increasing the capacity of the cable, so far as the heat is concerned, appeals to me on account of my experience there. We made many duct conduits in the early days, some of them as many as 36 ducts, and we found the cables in the middle of those many-duct lines would have an exterior temperature rise of 50, 60 or 70 deg. fahr. to begin with, some of them more than that, so that you can see that the problem of getting rid of the heat, particularly the heat in those conductors which ran in the interior ducts of the conduit, became a very serious one. They have even gone so far as to circulate water in some of the ducts in order to get rid of the heat. This is really an important problem, particularly where large amounts of power have to be dealt with at relatively low voltages.

F. L. Rohrbach: Regarding the cost of underground systems which would include a duct and manholes, I do not think there is any question but what Mr. Nims has used the cheapest method in his system at Vancouver; but I ask Mr. Nims if he has considered the case of using ducts and leaving out manholes (except those necessary for switching); also the use of lead-covered cables, and what that would mean. I suppose this cable could be exposed at points where the manhole would naturally be built, so that in case of trouble it will only mean digging down at each manhole, or where the manhole should be, and pulling out the cable that is in trouble. It would mean also that you could watch the size of your cable; and when necessary it would be easier to take out a small cable and replace it with a larger one. Now, I do not know exactly the difference in cost between this steel-armored cable and lead-covered cable, but judge it would be about ten cents per foot, that is, for the same size cable used with the steel armor and cable used in duct. Where you have three ducts in one line, they can be laid cheaper than three lines of single duct—I would figure the saving in cable roughly at ten cents a foot; thus lead-covered cable would be probably $7,300 cheaper. Another place you could save would be in the cost of the straight-joint boxes; that would be $1100 over the other method, as I understand these boxes are a means of connecting the armor on each side of the lead sleeve and keeping it continuous.

I do not understand the items under the " six railway crossings " and " ninety-six street crossings." There are no lengths given and I have no idea what the total distance is. If they are ordinary streets of 75 or 100 ft. it seems to me the cost is high, as I understand that is where the wooden duct was installed. Of course I know nothing about the labor costs in Vancouver, but here in Spokane I would estimate that a single fiber duct surrounded with concrete could be installed for about sixteen cents per duct foot, and wooden ducts for twelve or thirteen cents. Of course my idea in installing this lead-covered cable, in a duct throughout the whole system, as well as at crossings, is simply for the purpose of being ready to pull out in case of trouble; and I think Mr. Nims will find that if there is a breakdown in the cable there will be some difficulty in locating the point of trouble. I have found that a good many Eastern companies in testing for trouble use what they call the " cut-and-try " method. That does away with any complex test. Most of them simply go out and cut the cable probably at the center and find out which half it is in and then trace it back. I think this would probably be the case at Vancouver, although there may be some other method of doing it. There is one method which is used by simply putting a current on the conductor that is in trouble and then reversing the current. You go along in each manhole with a compass held close to the cable, and when you come to the point where your compass does not vary, you have passed the point of trouble and you know which section it is in; but you would be unable to do that with armored cable.

I suppose that Mr. Nims has certainly considered the conduit and manhole construction, and if he has I would like to hear approximately what the difference was in his estimates, and also if he has considered the duct alone, leaving out the manhole, because it would be a simple question to leave a four-foot section and have your joints there so that you could easily get down and uncover your cable. Of course I understand that by doing this you would have to cut your cable up in smaller pieces, have more joints, but you would get rid of making your additional joints over your lead-covered cable which you do with these straight joints. I think that here in Spokane I could come pretty close to this total cost, and put in a single duct, leaving out the manhole.

There is another question: Mr. Fisken said something about a large number of cables. I think it would be entirely out of the question to put in many cables; in fact, I do not know but what four would be too many, and especially as the size of the cable is not stated; for it would depend entirely upon the size of the cable. When you get a cable from about 1.2 inch to 1.7 inch the additional cost of the armor runs up considerably, varying from ten cents if the lead sheath is 1.2 inches in diameter, up to 19 or 20 cents, going up very rapidly to 1.7. The cost of the duct in fiber (fiber and cement) is about 16 cents; that is not including the trenching because I have taken for this estimate that the trenching, is already done; I have only taken the cost of installing the duct, which will run from probably 16 cents down to 10 cents, depending on the number of ducts. A wooden duct would be cheaper, possibly from fourteen down to seven or eight cents.

The amount of heat dissipated by this cable is placed approximately at 15 per cent over one working in a conduit. I would like to ask Mr. Nims if he has made this test, whether it is between armored cable in a duct and armored cable in the ground, or whether it is between armored cable in the ground and lead-covered in the duct. The additional insulating (jute) over the armored cable would probably cause an increase in heat of seven or eight per cent; that is, it would be harder to get rid of the heat due to the doubling, practically, of the insulation.

And regarding electrolysis, there is no question that the armor would be some protection against electrolysis, but still if electrolysis was present the armor might give way and the lead would possibly be eaten up, or if electrolysis was not sufficient to eat away the armor it probably would not injure the lead so quickly.

C. S. MacCalla: I had a little indirect experience some years ago in the system which was in the city of Sydney, Australia. The New South Wales government owns and operates the street railways in Sydney, which is a city of about three-quarters of a million; I happened at that time to be working for an American contractor who was installing a three-phase generating apparatus and substations. The cable was placed by an English contractor; it differed from Mr. Nims's cable and was considerably inferior to it; it had no iron armor and no insulation outside other than a little bitumen. The cables were laid in open trenches, I think about as many as eight in a trench, and were surrounded with a bituminous material and covered with treated plank. This cable was installed some months before the generating apparatus was ready for operation, and when they came to put the current on we had all kinds of trouble; and when investigated it was found that electrolysis had destroyed a large portion of the cable. If I had been the operating man at that time I would have been very thankful for a few ducts to pull out the cable. The whole city, which was largely paved, had to be dug up, the streets were torn up for some time, and the system had to be practically relaid.

H. V. Carpenter: I have had a little experience along this line, and I might state one instance which shows the durability of the steel armor. We have one cable line across the college campus, in which the cable is laid about two feet underground; during the excavation for our new engineering building recently they got over the line too far, and I found them tugging away at the cable with a plow and team, but they hadn't damaged it, so we moved it over out of the way. The cable showed no injury at all. It seems to me that in cases of that sort, where it is in a park or some place where there is no pavement, and there is no danger of electrolysis or any of those things, the use of the buried cable is very satisfactory.

Regarding the location of faults, I would like to say that the system which is now in use quite commonly by water companies, for locating troubles in pipes, could be used for locating faults in this cable. That is, put a current through the cable to the point where the fault occurs, and then take a coil with a good many turns on it and connect up the telephone receiver, walk along the ground over the cable, find the fault and dig it up and fix it.

P. M. Lincoln: About that last-mentioned method of locating faults—I have had some experience with it. That very same scheme was tried by the Niagara Falls Power Company back in about 1896 or 1897, and the trouble we found was that the location of the fault thereby was not definite. There would be at the point of the fault a slight diminution of sound in the telephone, but you would hear the telephone still buzzing for five hundred feet beyond the fault, and we found that the location of the fault was so indefinite that we had to abandon that scheme and locate our faults by some other method.

H. V. Carpenter: I think the accuracy with which that location could be made would depend considerably on whether het inductive coil was working by electrostatic action or by electromagnetic. If a current of sufficient strength is put through the cable to the point where the fault is located, so that the action is not electrostatic, then the trouble would be located quite accurately.

P. M. Lincoln: The influence of the cable upon the telephone is due to electromagnetic induction entirely, and the difficulty was undoubtedly due to the fact that the current, after it left the fault, followed the cable and got away into the ground rather gradually and the telephone would not distinguish whether the current flowed in the copper conductor or in the lead sheath.

Edward Woodbury: The paper states: "Water for cooling is taken from the city mains." I wonder if they waste that water or whether they attempt to save it. We have a small pump and cooling tower and the water is circulated; then for an emergency we have a city supply and in case the motor stops running the city water is turned on automatically.

G. B. Rosenblatt: Regarding water-cooled transformer substations, I wonder whether, where Mr. Nims comes from, they have any trouble with their cooling system from freezing. The matter of climatic conditions might be of further interest. I wonder how much freezing of the ground they have to contend with when they have any repair work to do in winter on the cable system.

John Harisberger: The use of cables in trenches without ducts appeals to me, especially as to first cost, if it is not intended to make numerous connections.

The problem of cooling water for transformers has confronted most operating companies. Use of city water is expensive, and a cooling tower is not a perfect arrangement. We have a rather novel arrangement in our Everett substation to prevent the waste of water. There are two pipe lines, one at 125 pounds pressure and one at 80 pounds pressure. The water for the transformer cooling coils is taken from the 125-pound line through a reducing valve which reduces the pressure to 90 pounds, and is discharged into the 80-pound line. This arrangement has proved quite satisfactory.

One of the gentlemen mentioned a cut-and-try method for locating trouble in cables. I wonder if Mr. Nims had any facilities for sectionalizing his 60,000-volt overhead lines, such as pole-top switches. If pole-top switches are used, has he found them satisfactory?

L. J. Corbett: This paper relates to the actual engineering features of an installation for a definite purpose. We can appreciate a difference between the installation for power alone, and one for both lighting and power. When the lines are opened temporarily or the voltage fluctuates due to some heavy load coming onto a system of the latter class, there may be a good deal of trouble caused, and complaints will be heard from the lighting customers. On a purely power load the fluctuations are not so noticeable, and while shut-downs may cause inconvenience, this is not comparable with a similar one on a lighting system, and for these reasons certain economies can be effected in the installation of such a system. Going still further, there are yet other systems which take greater liberties. In the case of a private manufacturing plant, for instance, which is generating or even buying its power and distributing it through its own system, liberties are sometimes taken with standard construction which would not be considered at all by a power company serving an exacting public. In Mr. Cotton's address which was given yesterday, we heard the term "near confiscation." We have in such cases as these at times a condition of "near unsafeness," and the limit is quite often approached rather closely.

I recently had occasion to make an estimate upon a system to use steel-armored cables, and found the cost to be somewhat more than that of lead cable and iron pipe conduit. The difference was not great, but it appeared to me to be in the wrong direction.

As has been brought out, quite frequently tests are made so closely that one can locate a fault within a very few feet, if the data regarding the length of line, distances, etc., are definitely known. In one or two of the cases just mentioned where the coil and telephone receiver were not successful, it occurs to me that possibly the reason for not locating the fault more closely might be this: If you have a large number of cables in a set of ducts, only one of which is faulty, your instrument will not be so sensitive as it would be in a case where there is but one cable, as in the campus system mentioned by Professor Carpenter.

Paul Lebenbaum: Relative to the advantages of sector as against round conductors, I know of an instance in which an operating company had a duct line that carried the maximum size of cable using round conductors, the number of ducts being limited by physical conditions. It being necessary to increase the capacity of this line, without resorting to a new route, cables of the sector type, having the same outside diameter as the round type, were substituted for the latter, and the desired increase in capacity was thus obtained.

E. Woodbury: I ask Mr. Nims if a sector cable costs more than the ordinary round type.

H. W. Carpenter: I ask how small size the sector cable is that is used; it occurred to me that if the sizes were carried down too low the corners of conductors would offer considerably greater tendency for electrostatic stresses to break through the insulation there than you would get with the round section.

F. L. Rohrbach: There is one company that I know of which does not recommend making a sector cable in which the conductor is less than 1/0. They claim that conductors smaller than 1/0 are apt to cause too sharp bends or points, which introduce the corona effect and sooner or later cause the cable to break down. This same company recommends an "oval" rather than a "sector" cable, especially for the smaller sizes.

These odd-shaped cables were first introduced for the purpose of saving duct space, and were therefore made in the larger sizes. For example, a 4/0 three-phase 15,000-volt ordinary cable is as large as you can install in a $3\frac{1}{2}$-inch duct, but by making a "sector" or "oval" cable, you can probably increase the conductor to 350,000 cir. mils. For my part, I can see no reason, but rather an objection, for making a small size cable in these special shapes. My objection would be that you decrease the circumference of the lead sheath, and thus cut down the radiating surface. I think this cable used at Vancouver was made in "sector" shape mainly to hold down the cost of the armor.

M. T. Crawford: I ask Mr. Nims what types of lightning arresters are used on the 12,000-volt lines of the system and what operating success has been secured. On 13,000-volt distributing lines for rural light and power on Puget Sound we have in some cases installed horn gaps without resistance of any kind and set for about three times line voltage. This type of equipment is only installed on the ends of branch feeders into rural districts where it has been necessary to keep the cost of construction down. Electrolytic lightning arresters are invariably used on the busbars in the distributing station. As the 13,000-volt feeders frequently run underneath 55,000-volt lines for some distance after leaving the station, there is the possibility of accidental contact between circuits, as well as the trouble from lightning to care for. A short circuit on the ends of these light capacity 13,000-volt lines will only trip the circuit breaker and cause a short interruption, which is preferable to damaging distributing transformers. I should like to hear other engineers' ideas on this subject.

F. D. Nims: There is one portion of the paper which apparently I have not made sufficiently clear. At the bottom of page 1302 you will find it stated "Where it is not required to lay more than four cables in a trench, the steel tape cable, laid directly in the ground, will be found to be cheaper than any of the other systems." This does not mean to indicate that I would advocate the use of steel tape cable in all cases. In fact, for more than four cables in a single trench I would probably put in a conduit system of some sort. I have a very vivid recollection of having trouble in a lead of 28 cables running out from a central station and the difficulties we experienced in tracing out the cables.

We find in testing for faults that the number of cables in the trench determines to some extent the accuracy with which we can find that fault. There is one method of testing which we are using at present which has not been mentioned, and that is by the bridge-megger. We find that with this on a 2/0 cable we can locate within about 130 feet. We isolate the section of the cable which is in trouble by means of the section boxes and test from both ends of the faulty piece. By this means we generally run our trouble down to within 75 or 80 feet. If there is a joint in the vicinity or if any digging has been going on we look at that first, but if nothing of this sort occurs we open our trench near where the fault is located and test with the "telefault." We find this instrument very good when we can get close to the cable with the exploring coil, but we cannot work it satisfactorily through twenty or thirty inches of earth.

As to repairs where cable is under the pavement; we have very little difficulty with that. After locating it requires a hole possibly three feet square to get down to the cable. The manholes or section boxes are used only for sectionalizing a cable or for cross-connecting cables. Everything is run out from the step-down transformers in rings or loops.

In regard to the street crossings and railroad crossings mentioned here, I will say that labor at the time the job was going on was costing $3.00 per 8-hour day. The duct under railway crossings, under the British Columbia laws, must be in concrete and that runs the cost up considerably. I will state in answer to Prof. Carpenter's question that No. 6 is the smallest conductor we use and very little of that; almost entirely 0 and 00.

Using city water for transformers costs us for a thousand-kilowatt bank of transformers about $8.00 per month. We have practically no freezing weather in Vancouver.

I am unable to give any figures on the difference in cost between the sector shape and round conductor cable. At the time we purchased our cable we were unable to obtain a sector-shaped conductor anywhere in the United States or Canada, so bought in England, so that it came into Canada under a preferential tariff. Where we would have to pay full duty from the United States on round conductors, it is difficult to get a line on comparative costs. I believe that the sector-shaped cable is now being manufactured in the United States, but only recently.

As for pole top switches for 60,000 volts, there is very little difficulty in installing them on steel towers, but on our present installation the line is so short that we have had very little occasion to use them. In fact it has been so seldom that we have found it about as easy to open the loop at a strain tower.

Referring to Mr. Crawford's question regarding lightning arresters: Electrolytic arresters are provided on the 12,000-volt lines where they have the station, but in no other place. We run these lines in some instances on the same poles with the 60,000-volt lines, but do not consider that with good construction there is any probability of accidental contact, and believe that the possibility of such a contact is so remote as not to warrant expensive protection.

In regard to electrolysis I will say that we have had practically no trouble with electrolysis in Vancouver, so that really up there we do not know much about it. We had a good deal of trouble in Mexico City with electrolysis due to the poor bonding on the part of the street railway company, but, as I have mentioned in the paper, we found that the steel tape type of cable stood up very much longer than the straight lead cable placed in a conduit right alongside on the same street, one on each side, originally laid by the two different companies which we took over. There was the same electrolytic action, but we pulled out the lead cable about three years before I left there, the steel tape cable remaining, and in those 3 years we had no electrolytic trouble. There was a slight electrolytic action on the armor, but not enough in any way to destroy its effectiveness. What Professor Carpenter said in regard to the strength of the cable we have found in several instances. I know we have had washouts and would have possibly 40 or 50 feet of the cable lying out with no support whatsoever, and would try to get into it with picks, try to hack it with axes, and all sorts of things, and it has been a pretty hard job to get through it.

We built a duct line, that is, going out of the station to the distributing system, at Mexico City. We had a fire some ten years or so ago when I first went there and my first job was to try and straighten out that tangle. When we tried to find out which cable was which it was almost hopeless, so finally while the service was interrupted we built a conduit run to take the cables outside the yard and got rid of the tangle.

Presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Spokane, Wash., September 10, 1914.

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ELECTRICITY IN THE LUMBER INDUSTRY

BY E. F. WHITNEY

ABSTRACT OF PAPER

The development in the application of electric drive to the lumber industry has been exceptionally rapid. Successful sawmill companies are now even operating entirely from central station service, notwithstanding the large amounts of refuse available for fuel.

The paper considers the lumbering industry as carried on in Washington and Oregon, and describes the application of electric power to the various operations carried on under the two main divisions of logging and milling. Typical applications are described, to illustrate types of motors and power transmission equipments, and the average power demands of the various logging operations and milling processes. In addition to the machines used in ordinary sawmill work, those used in planing mills and shingle mills are described. The question of the disposition of waste is considered, and comparative fuel values are given. The illustrations show logging operations and electrically driven saws, finishing machinery and lumber-handling machinery in the Pacific Coast lumber districts.

THE first comprehensive applications of electric drive in the different branches of the lumbering industry are of such recent date, and the individual installations vary to such an extent, that no general treatment of the subject could be undertaken until more well-defined practises were settled upon.

Not more than four years ago a completely electrically-operated sawmill was considered a hazardous undertaking; today, a new mill adopting other than the electric drive is the exception. The results of such operation have been so gratifying that today we can show two large and successful sawmill companies operating entirely from central station service, in spite of the large amounts of refuse available for fuel.

The first completely operated mill was put in operation about 1908; the total installation consisted of 800 h.p. connected load, with a generating plant capacity of 600 kw. The first electric logging engine was put in commercial service in 1912. The electric railway, used solely for logging purposes, is yet to come.

Before the above date many special machines—and often complete planing mills—were driven electrically, but none were willing to pioneer such drives for the heavy duty sawmill machinery required for Coast conditions. There is necessary today but one further step, viz., a drive for the cumbersome log carriage that will compare favorably in first cost with the simple twin engine, and the necessity for steam will be entirely banished from the milling branch of the industry.

The lumbering industry, as a whole, must be divided into two distinct classes of work for our consideration: logging and milling.

Under the first heading we have the following operations: felling the trees: cutting to desired lengths: gathering from the woods: loading: hauling to distribution centers: unloading: sorting: rafting and towing.

Under "milling" come the manufacturing plants and their various processes, which must be divided into: saw mills: planing or finishing mills: specialty mills.

The Pacific Coast and Northwestern States, together with British Columbia, contain two-thirds as much standing timber as there is in the entire United States; Oregon contains approximately one-fifth, Washington one-seventh and California one-seventh. In lumber production Washington, Oregon and California rank, respectively, first, fifth and fourteenth and their combined output is one-fifth of the total cut of lumber in the United States. The sawmills alone in these three states require approximately 240,000 h.p. for driving their mill machinery. Further than this, in the two northern Pacific Coast states, viewed from the point of manufacturing industries, the lumber production is of even greater importance; for instance, in 1913 the value of the lumber mill output in Oregon was approximately one-third of the total value of the manufactured products in that state.

LOGGING

In the branch of the industry embraced under the heading "logging", progress in the application of electric drive was very slow. It is only of recent years that power-driven logging machines have met with general favor, supplanting the old ox team. The flexibility of steam engines under the very severe demand imposed in such work, was thought to be an insurmountable obstacle to the adoption of any other system; for instance, the loggers demand an equipment which can stand very heavy overloads momentarily imposed and which, at the same time, has flexibility enough to allow the progress of the log to be stopped almost instantly should it encounter an obstacle.

At the present time it is estimated that there are approximately 3000 steam-driven logging engines in the two states of Washington and Oregon. Most of these outfits are twin-cylinder engines approximately 10 by 12 in. (25.4 by 30.48 cm.). The average operating boiler pressure is 160 lb. (72.5 kg.) gage, so that they have great capacity for intermittently imposed heavy overloads. From the viewpoint of electric operation this requires a motor which will seldom come anywhere near its continuous capacity, but which will frequently be called upon to exert its maximum torque.

In these two states the operating companies total 532, with an output of 7,080,000 M. ft. (board measure) or about 23,600 M. ft. (board measure) per day. The scene of their operations is often far removed from railroads; in the above operations the average distance from the scene of logging operations to the mill or to tidewater, varies from one to 35 miles (1.61 to 56.3 km.). The average distance is approximately 15 miles (24.15 km.). The maximum distance of which we have record that logs are handled by rail in either of these two states, is 120 miles (202.1 km.), and by towing—after reaching tidewater—125 miles (210.1 km.).

An added drawback to the use of electricity in the camps was discovered in the distance of the operations from the centers of power generation or present transmission lines.

Logging operators demand the simplest possible outfit, which necessitates the adoption of alternating current for such work.

The average cost to the logging company of logs at the boom is approximately $8.00 per M. ft. board measure. This is divided approximately as follows:

Fixed charges	17 per cent
Logging (including felling trees, gathering and loading)	50 " "
Hauling by rail	11 " "
Handling at boom (including unloading, sorting, rafting and towing)	9 " "
Stumpage	13 " "

We therefore see the great expense to the logger in felling the trees and gathering them from the woods, and in hauling them to tidewater. It is in connection with these two items that electricity has its greatest possibilities.

There has been developed, for the logging engine, a motor which has all of the characteristics demanded, viz., heavy construction; ability to stand severe overloads; ease of control and no complicated parts. After exhaustive tests the Potlatch

Lumber Company put the first two electric logging engines into commercial operation in 1912*. These outfits operate on an overhead system, lifting the logs from the ground and letting them come in practically by their own weight in hillside work, or pulling them in when working in flat country. Typical operating data are given in Mr. Barry's paper.

MOTOR EQUIPMENTS

The motor equipments shown in Figs. 1, 2 and 3 are adjustable-speed 150-h.p., 600-rev. per min. synchronous speed, 550-volt, three-phase, 60-cycle induction motors. Power is received at portable transformer substations—one substation for each equipment—at 11,000 volts and is stepped down to 600 volts for use at the motors. See Fig. 4. Rubber-covered armored cables run along the ground from the substation to the motor, the distance never exceeding 1000 ft. (304.8 m.).

In order to prevent mechanically over-taxing the equipments, an inverse-time-limit overload oil switch is set to give practically instantaneous operation when the pull upon the main cable reaches its breaking strain. For quickly starting or stopping and to prevent overwinding the cable, a solenoid brake is mounted on the front end motor shaft extension.

These outfits are also called upon to load the logs on cars and to spot the cars, and even under these conditions the electrically operated outfits hold the camp record for a day's operation, viz., 55,000 ft. board measure, gathered and loaded by one logging machine in one day. This quantity is comparative only to this company's other operations; the capacity of steam donkeys under similar circumstances is 40,000 ft. per day.

The following table gives representative performance figures for the various operations:

WORK PERFORMED	INPUT	DURATION.
Tightening standing line, 2800 ft. of 1½-in. steel cable	260 kw.	10 sec.
Running trolley out	Accelerating, 100 kw.	
	Running free, 35 kw.	40 to 60 sec.
Pulling trolley in with logs;		
1 log, 800 ft. b. m.	70 kw.	40 sec.
4 logs total 2000 ft. b. m.	145 "	65 "
3 " " 1600 ft. b. m.	210 "	60 "
1 log " 1100 ft. b. m.	85 "	70 "
1 " " 1800 ft. b. m.	95 "	90 "
Loading logs on cars	max. 100 "	
	min. 70 "	3 to 5 sec.
	avg. 85 "	
Moving cars	max. 225 "	
	min. 25 "	3 to 5 sec.

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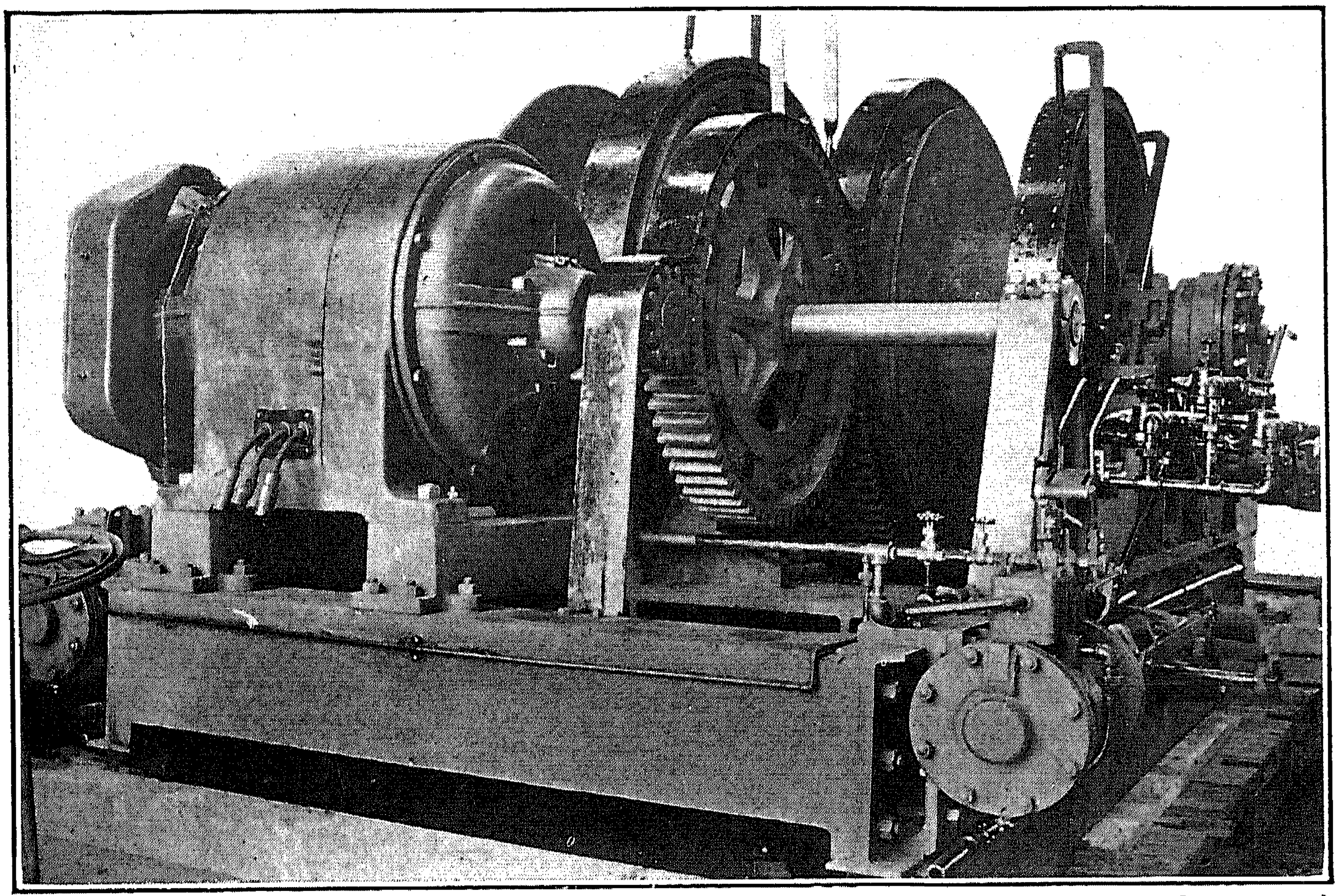
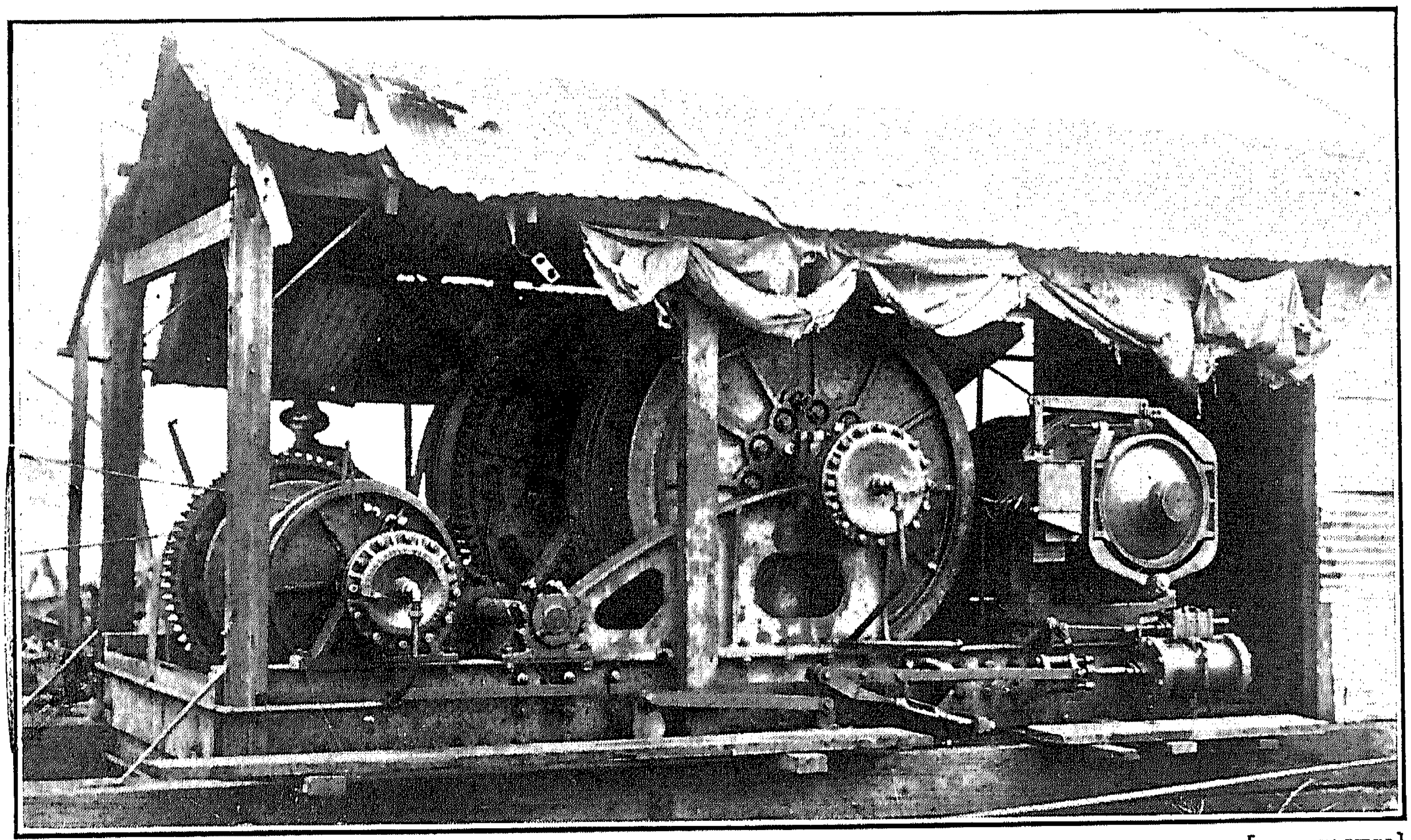
*E. J. Barry—A.I.E.E. PROCEEDINGS, September, 1913.



[WHITNEY]

FIG. 1—FRONT END, ELECTRIC LOGGING ENGINE



[WHITNEY]

FIG. 2—ELECTRIC LOGGING OUTFIT MOUNTED ON SKIDS AT SCENE OF OPERATION

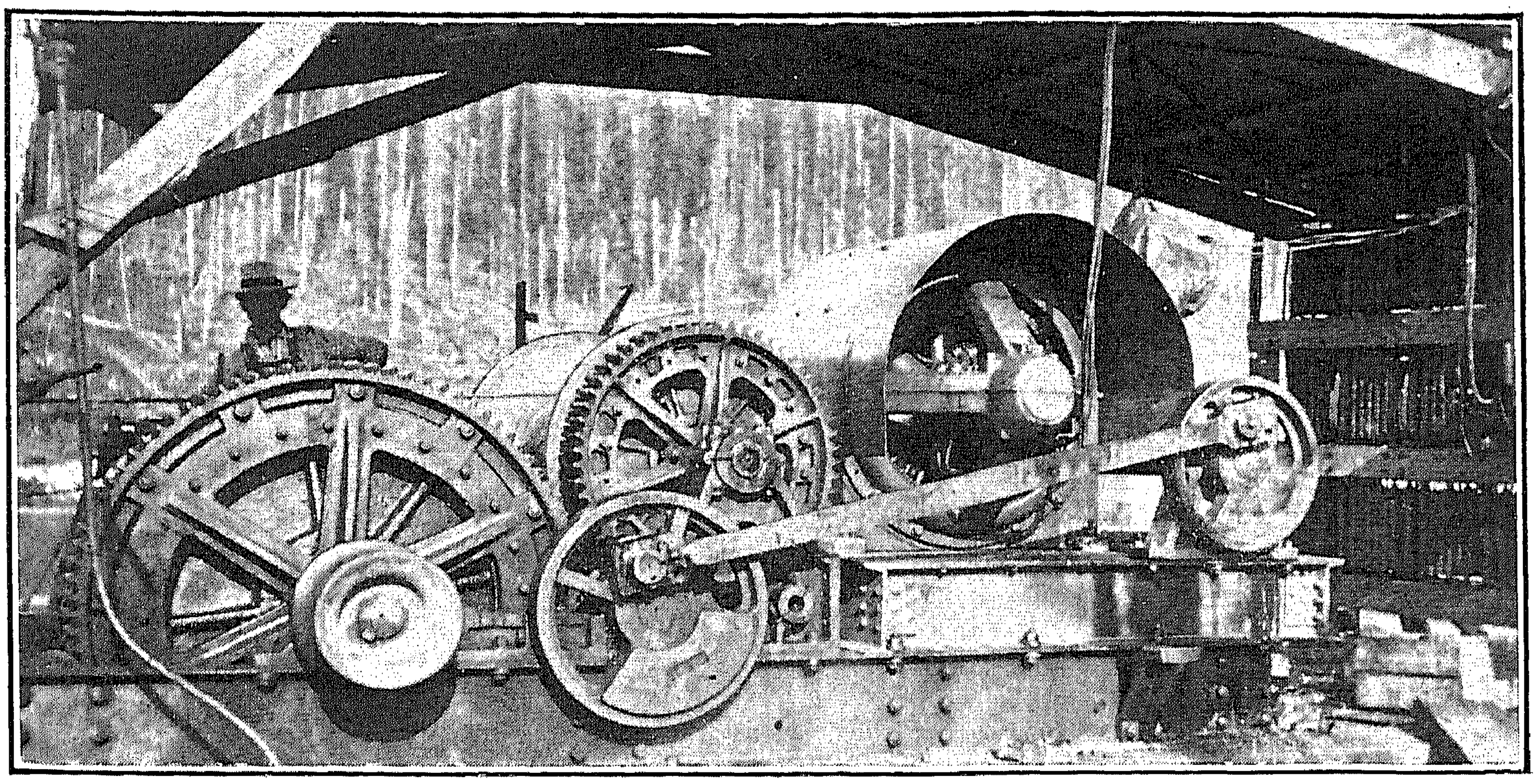


FIG. 3—FIRST TRIAL OUTFIT, USING STANDARD MOTOR EQUIPMENT

This outfit operated successfully under varying conditions for a period of three months, to obtain data for later applications.

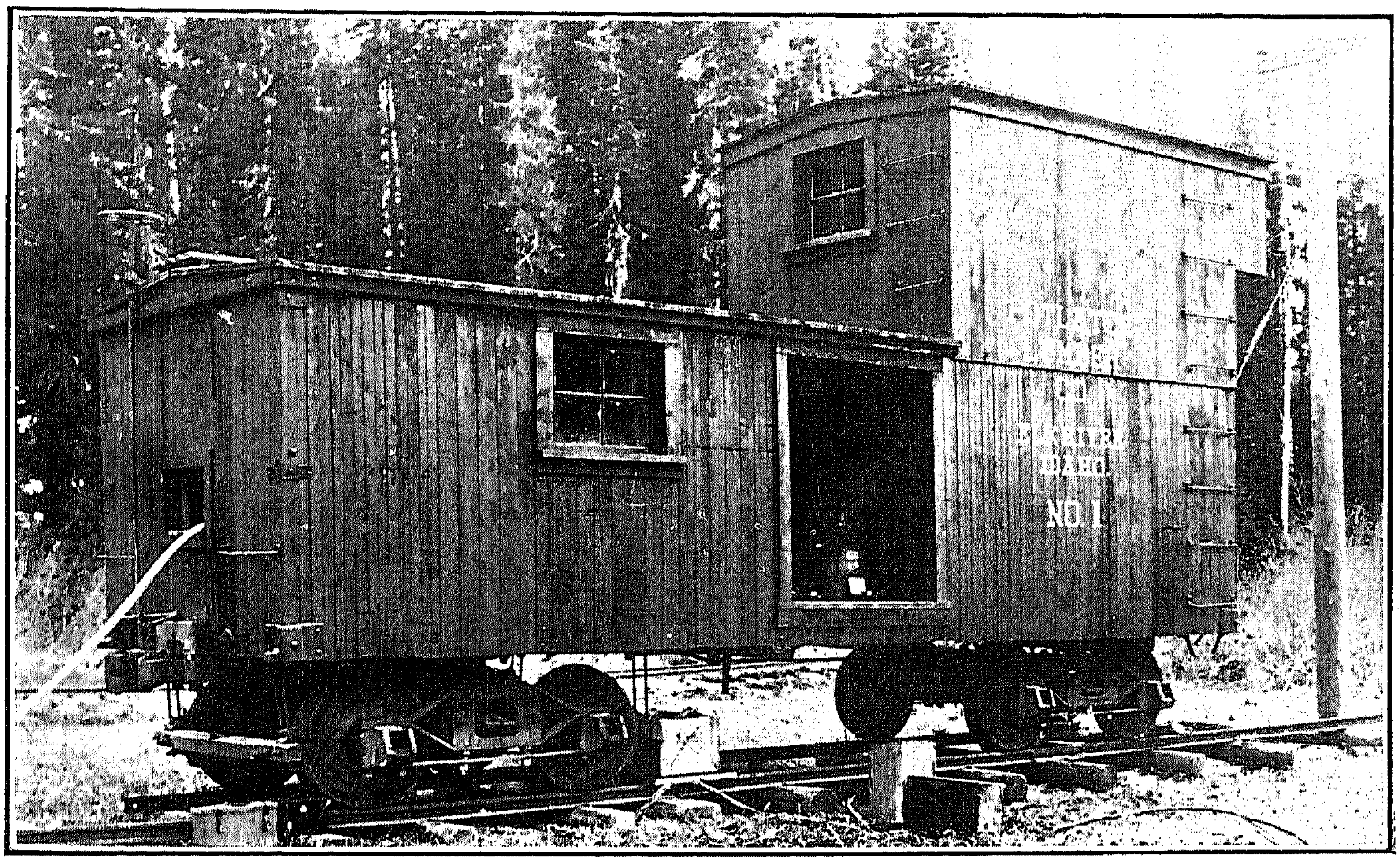


FIG. 4—PORTABLE TRANSFORMER SUBSTATION, 11,000 TO 600 VOLTS. ARMORED CABLE LEADING TO LOGGING ENGINE AT LEFT

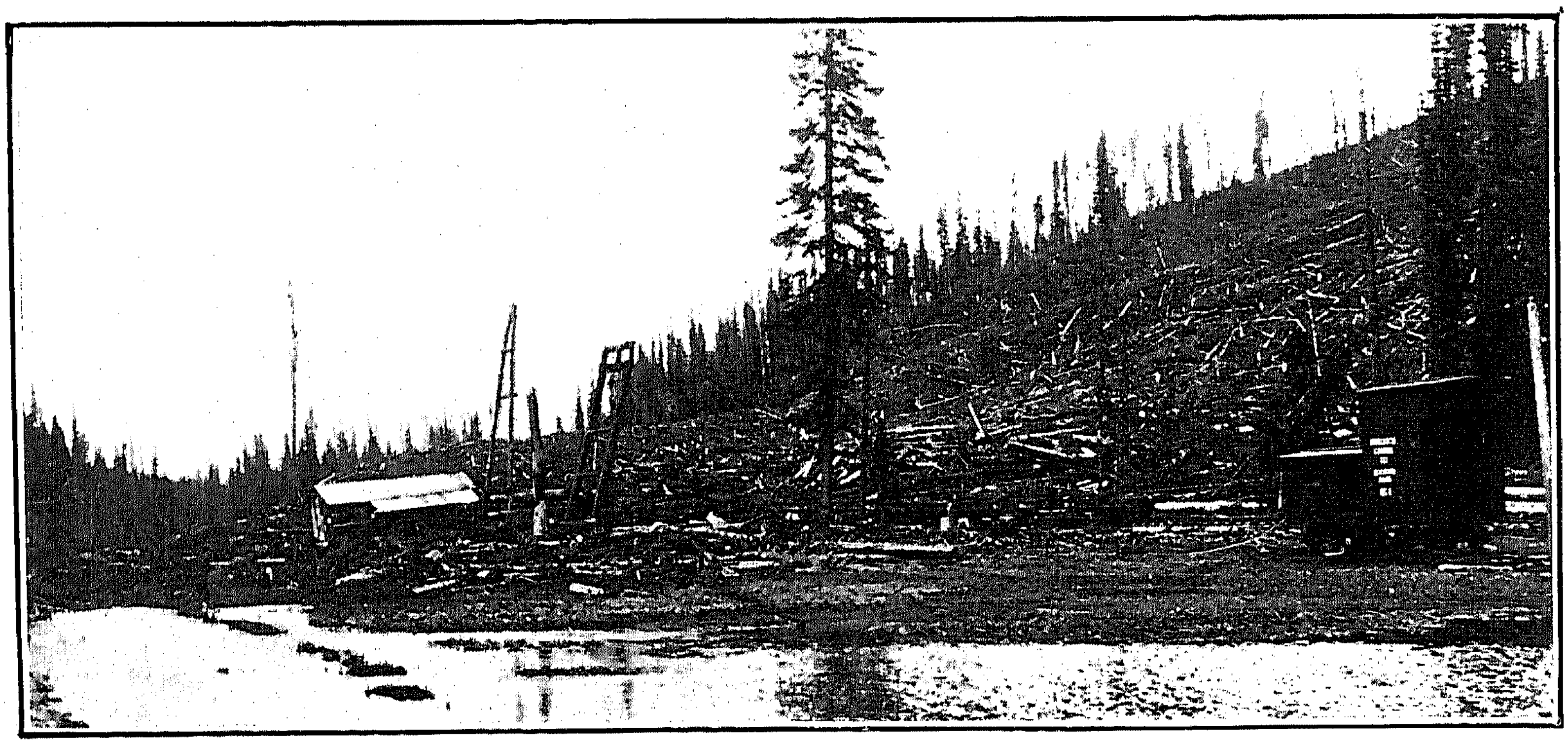


FIG. 5—GENERAL VIEW OF POTLATCH LOGGING OPERATION. ELECTRIC LOGGING ENGINE AT LEFT, SUBSTATION AT RIGHT. [WHITNEY]

In all of the above operations the load is of short duration, so that the daily energy consumption is small. For a 10-hr. day approximately 400 kw-hr. are consumed gathering and loading 50,000 ft. b. m. Fig. 5 shows a typical logging scene in this country. Fig. 6 shows the type of equipment adopted by the C. A. Smith Lumber & Mfg. Co. It is intended for hauling logs on the ground by the old method of "skidding". The motor is wound for 2200 volts. This pressure has been adopted by this company as most economical under its conditions, which require that it cover at least one mile in every direction from a distributing point, to several operating locations. A permanent 60,000/11,000-volt substation in the center of its holdings will distribute to three or four 750-kw., 11,000/2200-volt portable substations, each feeding one unit of its operations.

Of late, a great deal of attention has been given to the use of oil fuel and coal, as well as wood, for logging engines, and in order to see the comparative operating costs the following figures, covering fuel and labor for a logging engine only, have been prepared. These figures are based upon operations under similar conditions in the same camp and doing the same general work.

Average quantity handled per day	76,200 ft.. b. m.*
" distance of yarding	670 " (204.2 m.)
" size log	1900 " b. m.*
" time per log	15 min.
" wood burned per day	1650 ft. b. m.*
" fuel oil per day	†8.8 bbl. (11,192 liters)
" coal per day	2½ tons (2.245 metric tons)
Electric power energy consumption	475 kilowatt-hours

Outfit working 70 per cent of time—delays 30 per cent of time.

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*In *lumber scale* 1 ft. b. m. is the equivalent of a board 12 in. (30.48 cm.) long, 12 in. (30.48 cm.) wide and 1 in. (2.54 cm.) thick, or 144 cu. in. (2359.7 cu. cm.). The *log scale* considers all items of loss in manufacture and endeavors to allow for these losses so that the log estimate and lumber production may approximately agree. It considers loss due to saw kerf, defects in log, varying diameters at top and butt, etc. There are several rules used in different localities—one will under-estimate the lumber in small logs—another will under-estimate large logs—and the third (which is rather generally used on the Coast) gives a mean value, approximating more closely conditions as found. The above values refer to log scale and therefore represent a greater cubical content than would be the case after same was manufactured into lumber. A very good comparison is given by the following:

1000 ft. b.m. log scale weighs approx........8000 lb. (3628.8 kg.)
1000 " " lumber scale (green lumber)...3300 " approx. (1497 kg.)

† 1 bbl. oil = 336 lb. (152.4 kg.)

ELECTRIC OPERATION:

475 kw-hr. at 1½c. per kw-hr.	$ 7.13
One motorman	3.75
Total per day	$10.88

OIL OPERATION:

†8.8 bbl. at $1.15 per bbl.	$10.12
Engineer	3.75
Water—(based on ¼ of pumping engineer's time and ¼ fuel consumption for pumping engine)	2.67
Total per day	$16.54

COAL OPERATION:

2½ tons at $4.25	$10.62
Engineer	3.75
Water (see Oil Operation)	2.76
Total	$17.13 (per day)

WOOD OPERATION

1650 ft. b. m. at $7.00 per M.	$11.55
Engineer	3.75
One wood bucket	2.75
Water (see above)	2.88
Total per day	$20.93

The fuel costs given above are arbitrary and are taken as general averages. It is questionable whether oil and coal can be delivered to the donkeys for such a low price, considering all items—handling, storing, pumping, etc. Without doubt, the cost of fuel would be higher than the value assumed, in the majority of operations. The cost of wood for fuel is estimated as follows:

Stump value	$2.50 per M.
Logging cost	4.00 " "
Extra cost for placing behind donkey	0.50 " "
Total	$7.00 per M ft. b.m.

The higher interest charge in the case of electric operation due to first cost of transmission line, substation, etc., is more than offset by the very much greater depreciation in the case of steam-operated outfits. No attempt has been made to cover this item for all cases. As a conservative estimate, however, the maintenance of a logging engine boiler 72 in. diameter by 144½ in. long, with 374 two-in. tubes, is not less than $200.00 per year, and in view of the severe service its useful life will not exceed eight to ten years.

Averaging the above costs for fuel and labor, with oil, wood and coal, shows a net saving of $7.35 per donkey per day in favor of electric operation.

An electric unloader is used which dumps the logs from the cars at tidewater. This is operated by a 37-h.p. hoist motor, and unloads 30 cars, each containing 7000 ft. b.m., in approximately 20 minutes. This time includes that necessary for spotting the cars at the log dump. This unloader used a total of 90 kw-hr. for unloading 4000 M. ft.

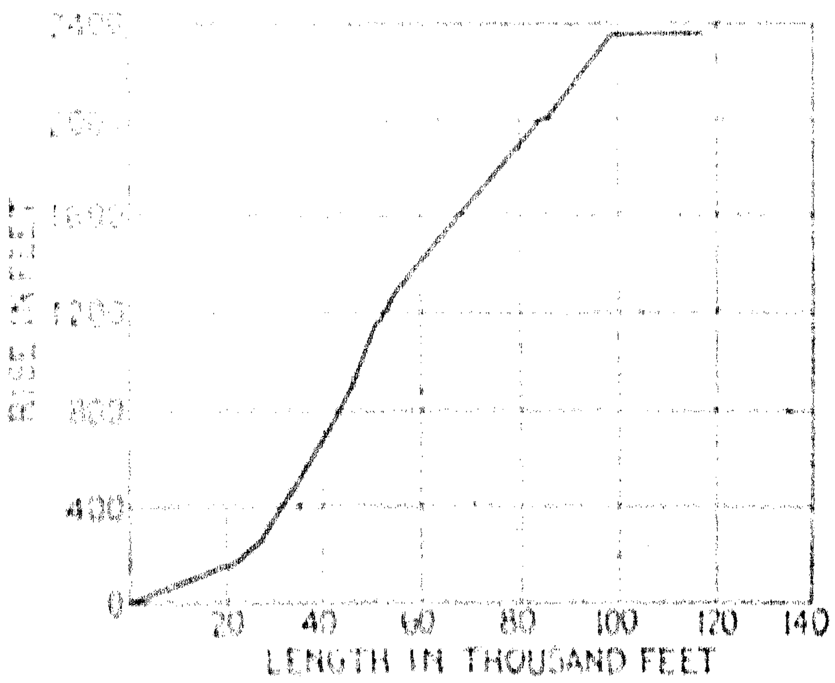


FIG. 7—PROFILE OF LOGGING ROAD NO. 1

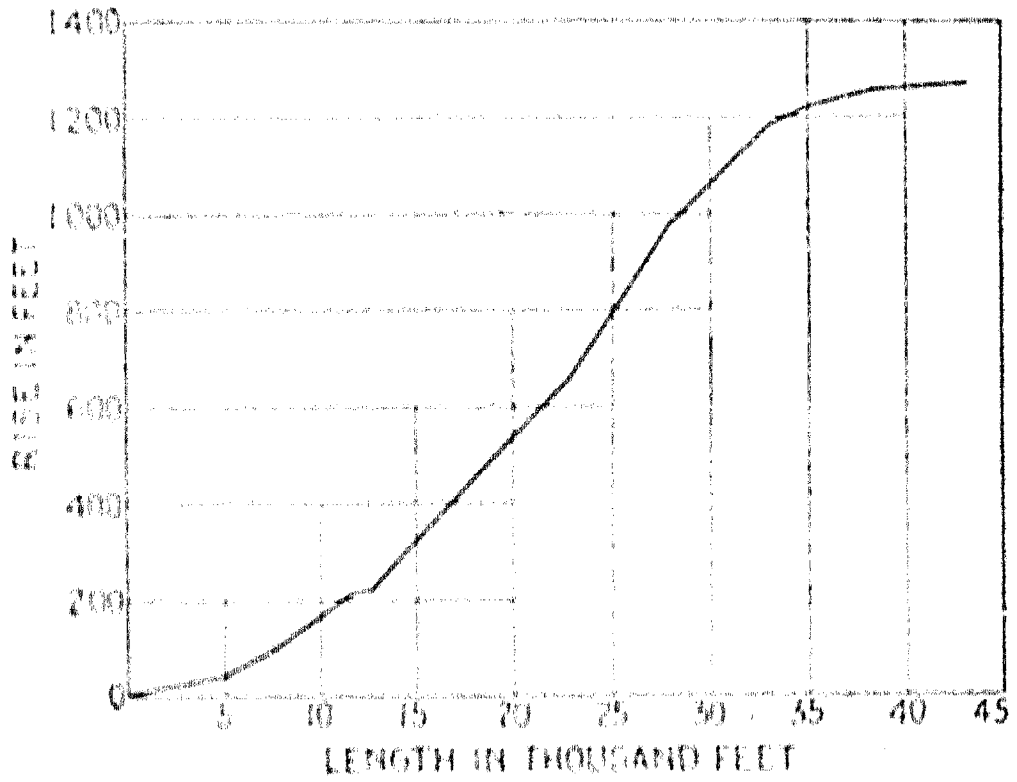


FIG. 8—PROFILE OF LOGGING ROAD NO. 2

LOGGING RAILWAYS

Figs. 7 and 8 show typical condensed profiles of two logging railways. Usually the country to be tapped is rugged and mountainous, necessitating heavy grades and sharp curves. Track construction is as light as possible. As a general rule the grade is in favor of the load and in most cases very little energy is required on the down or loaded trip. Oil is the common fuel. Because of the grades encountered slow speed locomotives find a wide use, the slow schedule speed requiring train operation almost continuously during working hours. The lengths of these roads are usually very favorable to electric operation, allowing a round trip to be made in a reasonable time and not necessitating a train of excessive length.

In only three of the thirteen counties in Washington and Oregon which produce 88 per cent of the timber in these states is the average length of haulage less than thirteen miles. An average of the thirteen counties shows a main line length of 15.2 miles. The maximum grades are usually from 5 to 7 per cent for an appreciable distance, with curves up to 20 degrees. The average grade through the line is seldom less than 2½ per cent and spurs leading to the different camps have even heavier grades and sharper curves.

An analysis of operation is very favorable to electricity, as will be seen by the following data, which give conditions of a typical road:

General Data:

Length of line	21½ miles.
Average grade with load and against empty cars	2 per cent
Maximum grade, including equivalent friction for curves	5.5 per cent.
Gage of track	4 ft. 8½ in.
Weight of rails	60 lb.
Loaded cars to be delivered per day	75
Weight of car empty	18½ tons.
“ “ “ loaded	50 tons.

OPERATION

Weight of locomotive	60 tons.
Cars per train either direction	9
Total weight of train uphill, one locomotive	226½ tons
“ “ “ “ downhill “	510 tons.
Total time for round trip without layovers or switching	144 minutes.
Schedule time for round trip	3 hr.
Round trips per locomotive per day	4
Ton-miles per round trip	15,800
“ “ “ day—8 round trips	126,400
“ “ switching	6,500
Kilowatt-hours per day at locomotive	6,110 kw-hr.
“ “ “ “ from high-tension bus	9,050 kw-hr.
Ave. load per day of 12 hrs. from transmission system	754 kw.

Three locomotives are required for this service, two main line and one for switching.

With 1200-volt electrification, two 500-kw. substations will care for the power demand. The total approximate cost of the locomotives, substations, transmission line, overhead, bonding and feeders is $190,000.00.

For similar operation with oil-burning locomotives, two 125-

ton standard slow speed freight locomotives and four 50-ton geared type locomotives are required, and even with this equipment the train must be broken at the heaviest grade, necessitating a return trip for a portion of the empty train which starts from the terminal.

The locomotives burn oil fuel, which costs approximately $1.15 per barrel for main line locomotives and $1.20 per barrel for switching locomotives at the logging camps. Electric power can be purchased for 0.9 cent per kilowatt-hour net.

The following table of maintenance and operation, omitting those items which are approximately the same under the two conditions, shows a net saving of $20,068.00 per year with the electric railway:

	ELECTRIC	STEAM
Interest and depreciation	$19,000	$ 9,200
Maintenance	7,168	10,436
Wages	10,200	21,300
Power or fuel	24,500	38,500
Supplies	1,500	3,000
Total	$62,368	$82,436

Under "electric operation" the different charges cover both substation and train operation. There are some items which ordinarily would favor electric operation—for instance, track maintenance has been considered the same in both cases and omitted from our consideration, since in logging railway operations the greatest damage to the tracks appears to come from the swaying of the loaded cars, and not from the locomotives.

With steam operation, 84½ bbl. of oil were used per day for main line haulage for the two 125-ton freight locomotives, and two 50-ton shays, and 22.3 bbl. per day for the two 50-ton switching locomotives. In this present instance the steam locomotives are taxed to their utmost capacity while logging operations are being carried on at the near end of the timber holdings.

It will be necessary within a few years for this road to be extended approximately twelve miles further, the prevailing grade on the extended line being the same as at present, and an analysis of the future conditions will show that four locomotives operating thirteen hours each per day will be able to care for the output and the conditions will then be very much more favorable for electric operation.

MILLING

Under the first heading will come all that part of the manufacturing plant which converts the logs into timbers or boards, including all operations—from taking the log from the pond until the rough manufactured product is sorted into its various dimensions and lengths, ready for storage or further manufacturing. These operations may be divided into the following branches: handling the logs: sawing: trimming and sizing: disposing of refuse: sorting: storing or shipping.

In order that the sawmill operator may more profitably dispose of his better grade stock, a finishing mill is a necessity and in reality such a more or less completely equipped mill is always understood to be included in the general term "sawmill". The operations are so distinct, however, that it has been thought best to include the planing mill under a separate heading.

In those mills which finish a large portion of their product, there is between the sawmill and planing mill a seasoning process, which we will term "treating". This consists of artificially drying the product before finishing it. Its object is to get the material to its ultimate seasoned dimensions before the final manufacturing operation. Those operators who must overcome the handicap of high freight rates secure an additional advantage in eliminating all excess weight due to moisture. Some specialty mills (shingle mills, for instance) resort to drying solely for the purpose of reducing weight.

The treating process includes: stacking: drying: unstacking: sorting.

For economy of space, the material must be stacked in some uniform manner; industrial type flat cars are generally employed, with mechanical means for loading the lumber upon these cars. With the old method of hand stacking, the capacity of two men per day seldom exceeded 10,000 ft. b.m., which is approximately 2000 boards.

When the electrically operated stacker is used, the boards are taken directly from the sorting chain and two men can care for from 45,000 to 50,000 ft. per day. The lifting arm of this equipment, which lifts each stack in position, together with a short section of the conveyer table, is operated by a $7\frac{1}{2}$-h.p. motor, belted to a line shaft and running continuously. The load factor is not more than 5 per cent. The peak when lifting the arm is approximately 12 h.p., while running the mechanism light requires 2 h.p.

The dry kilns universally follow the old principle of steam radiator construction. The steam legs of the radiator are made up of a large number of small pipes, one in. (2.54 cm.) to 1½ in. (3.81 cm.) in diameter, which run the length of the kiln and connect to steam exhaust headers at the end. A typical dry kiln layout is shown in Fig. 9. It is common practise to admit high-pressure steam directly to the pipe. Of late years the vacuum system, taking exhaust from the mill engines at 5 to 30 lb. (2.2 to 13.6 kg.) gage and exhausting into 20 to 25-in. (50.8-to 63.5-cm.) vacuum, has come into rather general use. Where high-pressure steam is used directly, a reducing valve which cuts the pressure to approximately 50 lb. gage is ordinarily inserted.

It requires about 72 hours for drying planing mill stock, and six days for drying bundles of shingles. After the kiln has once reached a constant temperature approximately 1000 lb. (453.5 kg.) of steam per hour are required by the average kiln.

In green lumber, 30 per cent to 40 per cent of the weight is moisture. The dry-kiln operation reduces this to from 6 per cent to 10 per cent after drying. The process is not carried further as there is no necessity of furnishing lumber drier than the air at the locality in which it is to be used.

After drying, the lumber is unstacked and distributed to the finishing machines. The scheme for unstacking edge-piled lumber in most common use consists of an endless chain with hooks spaced about 10 ft. apart, running in vertical guides, these guides at the top being curved to direct the boards on to a conveying table. As the hooks revolve, they engage the bottom of the stack, lifting it from the car, and the top guides direct to a transfer table, from which it goes to the sorting table and is classified and taken to the finishing machines. This unstacking device is driven by a 5-h.p. constant-speed motor and requires approximately 4 h.p. while lifting the stack and 1¾ h.p. running the lifting and conveying chains only. Its unloading capacity is approximately 60,000 ft. b.m. per day.

PLANING MILL

Operations in this mill consist of planing or finishing the stock, trimming, disposing of refuse, sorting, tying or bundling and storing or shipping.

The product of this mill comprises the highest grade lumber and is consequently given close attention.

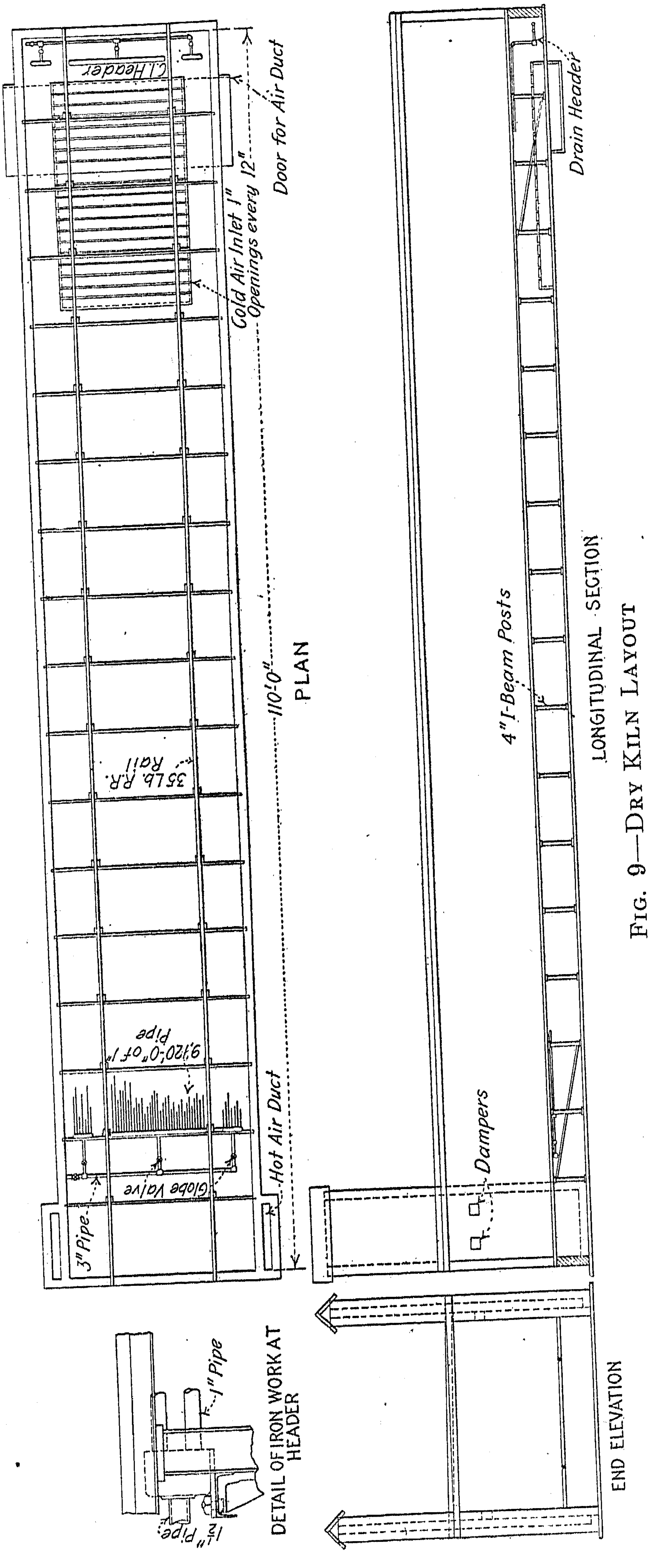


FIG. 9—DRY KILN LAYOUT

Before planing, it is often necessary to do a small amount of re-saw work, but this is of a very light character, its purpose being to re-manufacture yard stock to supply the accumulation of orders for any one size of lumber. The refuse from this mill is the best fuel supply, since it is thoroughly dry.

SPECIALTY MILLS

Specialty mills are often valuable adjuncts in utilizing materials which would otherwise be thrown away as refuse. Very often they have no connection whatever with sawmills and must purchase their material in the open market. In the following, therefore, we have considered only those specialty mills which have a direct connection with sawmills.

LATH MILLS

Lath mills are always run in connection with sawmills and obtain their material from slabs and edgings which would otherwise go to the refuse burner or, at best, to the wood bins. The slabs are taken from the main refuse conveyer and go through the following processes: bolter: lath machine: trimming, bundling.

Bolting consists of sizing the slab to the dimensions necessary for putting through the lath mill. The bolter may consist of a number of saws, therefore making several bolts at one operation, and requires about 7½ h. p. per saw.

The lath mill consists of three saws, making four laths of each bolt, and requires approximately 25 h. p. The laths are then trimmed to 4-ft. (1.21-m.) lengths and tied in bundles of 50 or 100, after which they are ready for storage or shipment.

SAW MILLS

In saw mill operations the work consists essentially in manufacturing a log to boards or timbers of a certain thickness, width and length, so in its elementary form only three machines to perform these functions are necessary. In the following, therefore, we will follow the progress of the work through the mill in its simplest form, afterwards returning to the auxiliary machines which have come as a natural result to increase production by performing some of the elementary functions faster or with greater facility than could be done with only the major machines.

In driving the mill machinery, squirrel cage motors are used wherever possible, because of their simplicity and strength. Unless specifically noted to the contrary, it will be understood that constant-speed, alternating-current induction motors are referred to. Practically all of the work is at constant speed, and in fact in sawing operations this is of prime importance. In the first installations, individual drive for each device or machine was used without question, thus, at one step, past practise with line shaft and belting, with all group drives, was entirely reversed, in an endeavor to do away with shafts, belts and transmission machinery entirely. Today, semi-group drive is standard. All parts which work to the same end and are close together, are grouped. Groups usually embrace such devices as transfer rolls, transfer chains, conveyers, etc., which require a certain amount of transmission machinery in any event, and which require practically the same power when running idle as when working. The milling machines themselves are individually driven.

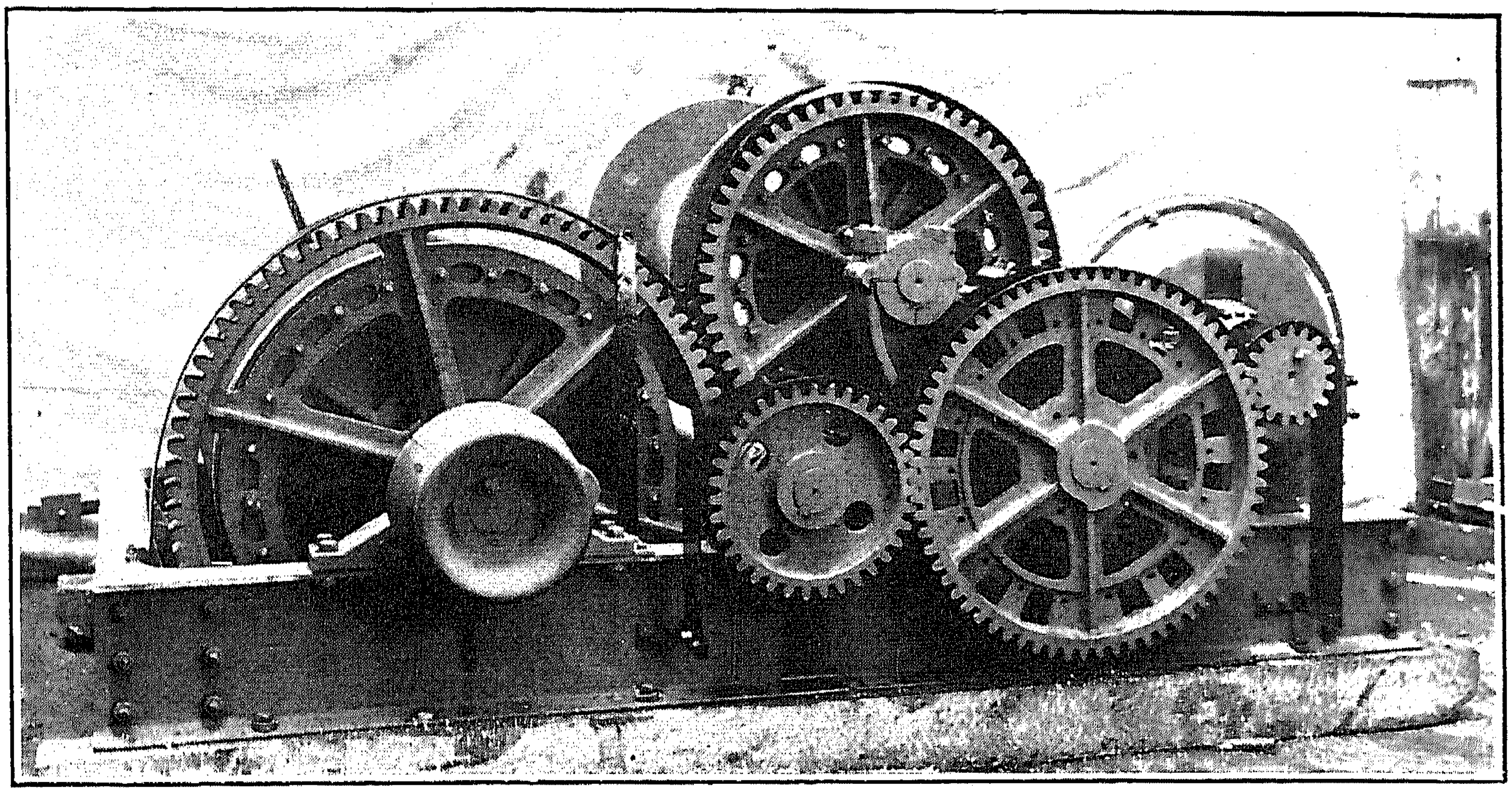
The power demands of the machines fluctuate so that it is practically impossible to plan for other than the maximum demand which might be encountered. For instance, an edger may run on narrow material with two saws cutting a two-in. board, and within five minutes, the same machinery may be called upon to handle a 6-in. (15.24-cm.) to 12-in. (30.48-cm.) cant, requiring four or five working saws, taking in the first place approximately 40 h. p. and in the second place 350 h. p.

In the following, wherever load factor is given, it is taken as load factor based upon the time of a working day. Some mills operate 24 hours, while others run 10 hours, and it is therefore obvious that unless the actual working time for each day is taken, the data will not apply universally.

Fig. 10 gives the general plant and yard scheme of a modern Pacific Coast mill. The logs as delivered to the pond are of various lengths and sometimes must be cut to accomodate the mill layout. This operation is performed more often when the logs are still in the water, but is sometimes done after they have been lifted to the log deck. Fig. 11 shows the saw used in the latter way. The driving motor is a squirrel cage type, 10 h. p., and is run intermittently. Its load factor is not greater than 6 to 7 per cent.

LOG LIFT

The logs are carried from the pond either by the old arched log haul, or by the later log lift (Fig. 12). In the first case an endless



[WHITNEY]

FIG. 6—LOGGING ENGINE OF C. A. SMITH LUMBER AND MANUFACTURING COMPANY AT MARSHFIELD, OREGON

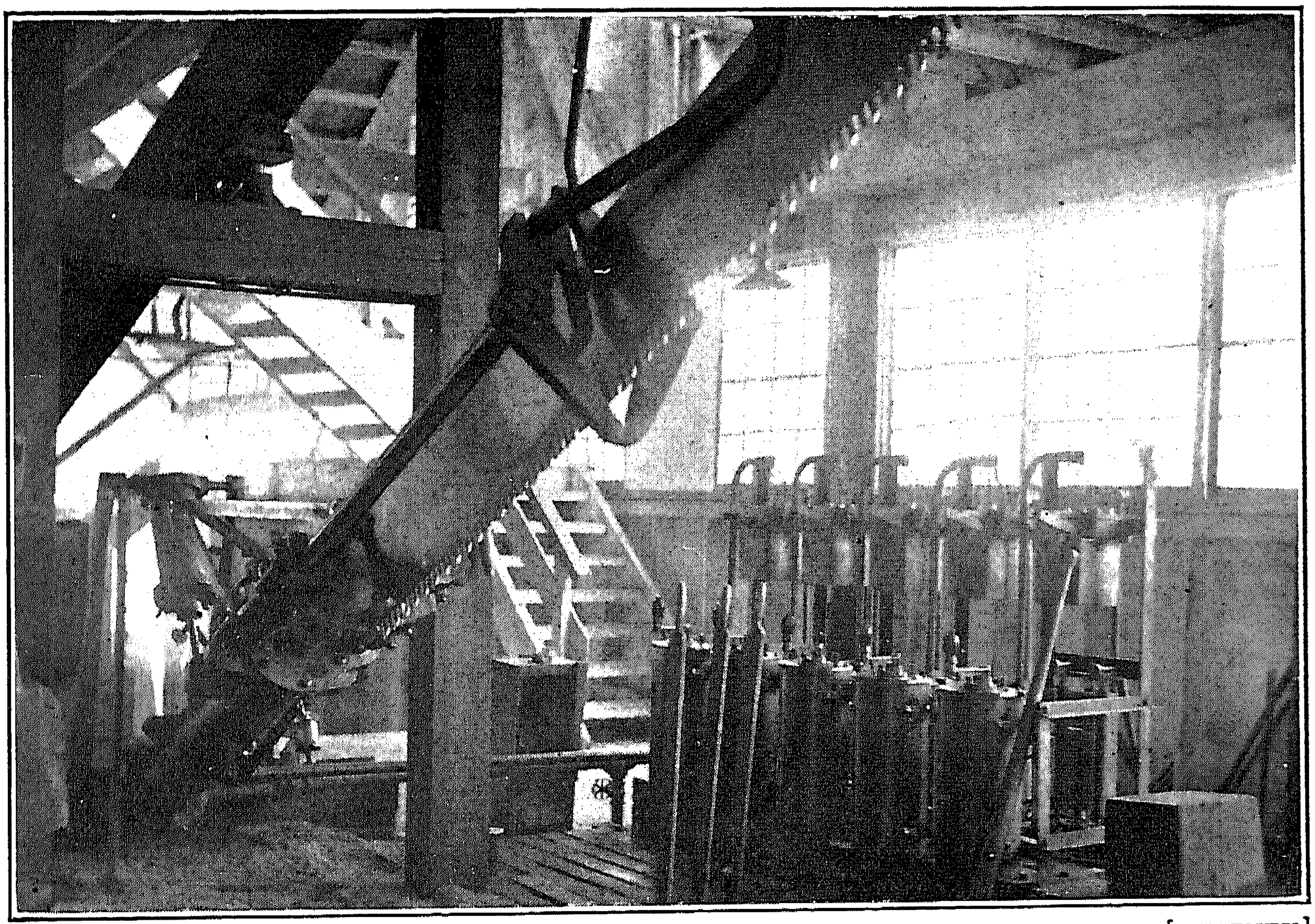


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FIG. 11—LOG SAW ON LOG DECK IN MILL. CONTROL FOR LOG HAUL AND CONVEYER CHAINS SHOWN AT RIGHT

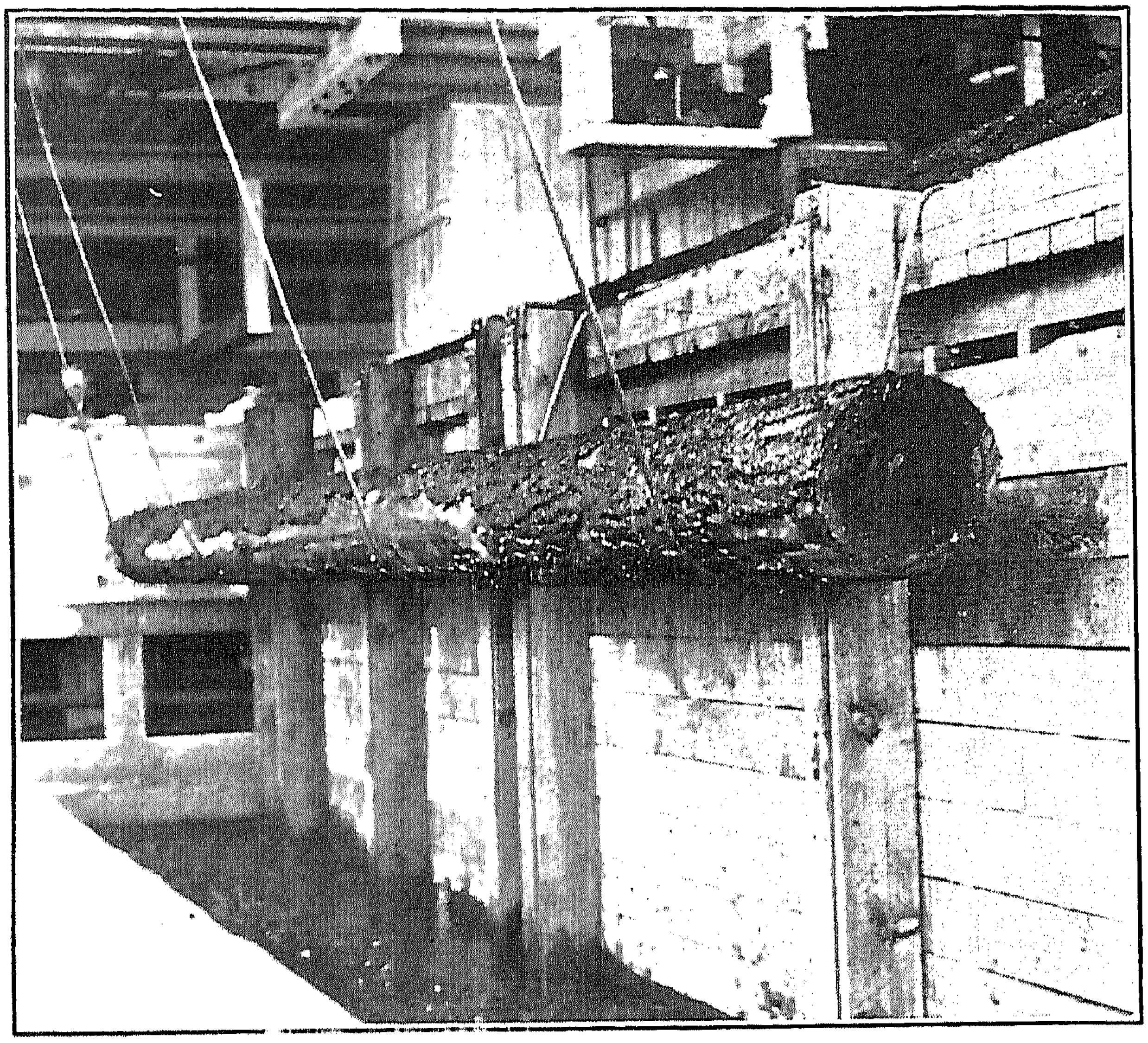

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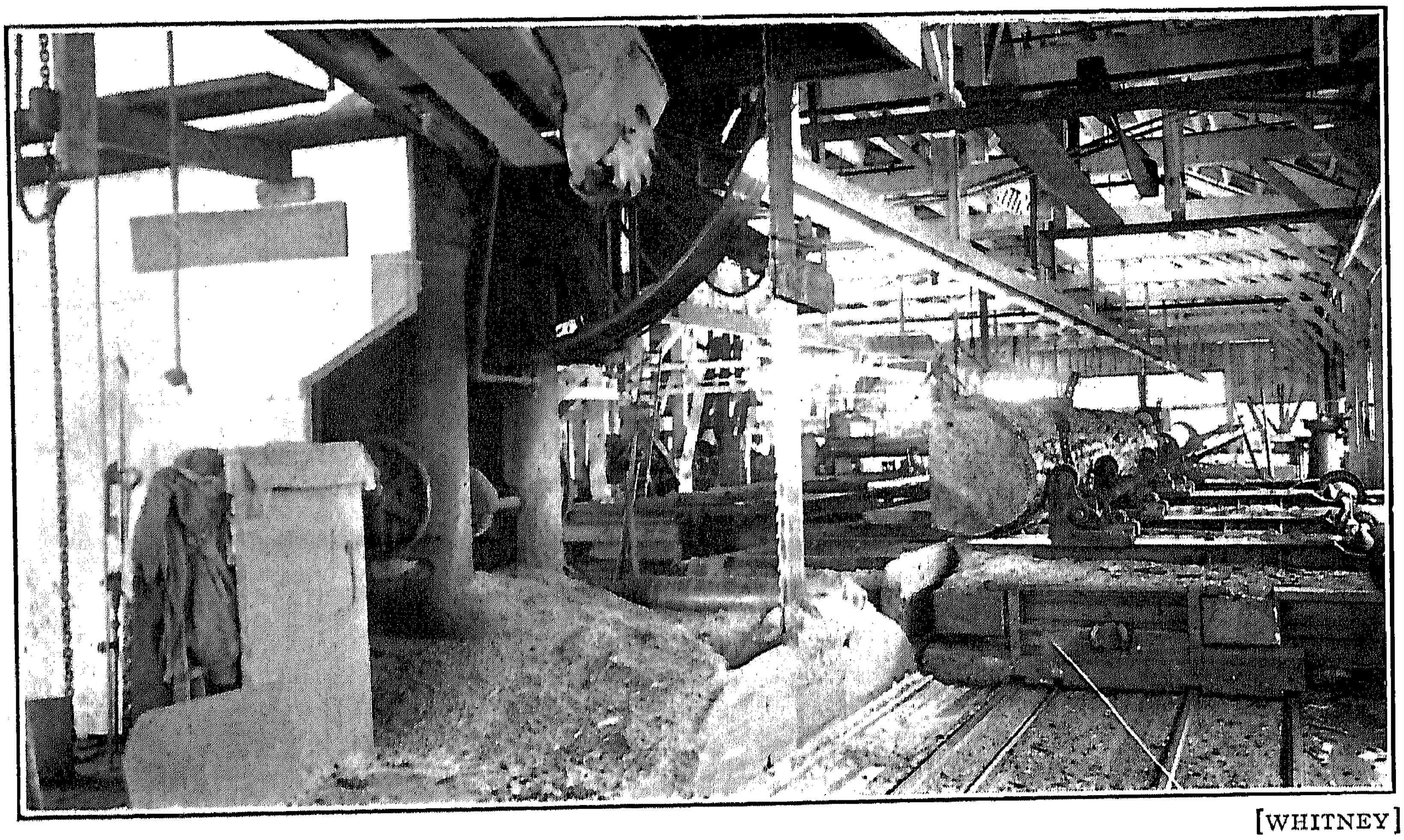
FIG. 12—LOG LIFT WITH LOG AT HALF ELEVATION



[WHITNEY]

FIG. 15—TEN-FOOT BAND HEADSAW AND LOG CARRIAGE AT END OF TRAVEL. BOARD WHICH HAS JUST BEEN CUT IS LYING ON LIVE ROLLS

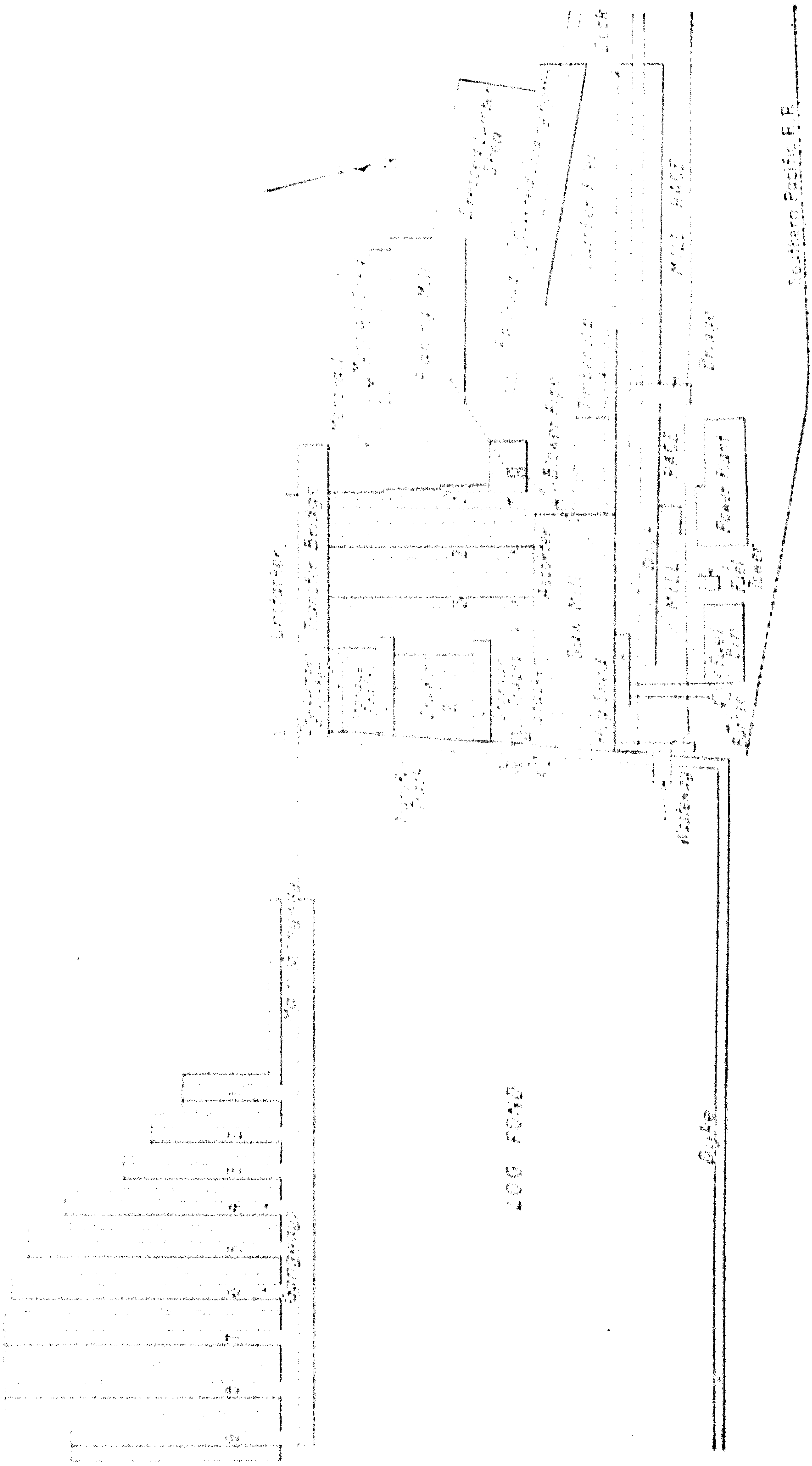


FIG. 10—YARD LAYOUT—BOOTH-KELLY LUMBER COMPANY

chain with hooks spaced several feet apart runs in a groove in the arched log haul structure, at a speed of approximately 50 ft. (15.25 m.) per minute. The driving sprocket is driven by a constant-speed squirrel cage induction motor of about 35 h. p., through the necessary speed-reducing transmission machinery. See Fig. 13. The motor runs continuously and the load is thrown on or off by the friction device. The log lift is coming into more general use, because of the upkeep expense of the older scheme of log haul.

A canal leading from the log pond is built into the head end of the mill, paralleling the log deck. Cables are attached to the edge of the log deck and fixed to hoisting drums overhead, allowing the loop to fall below the surface of the water in the canal. The logs are floated in and then hoisted, the natural angle of the cable as it becomes taut at the end of travel rolling the logs on the deck. An intermittent-duty hoist-motor, with reversible controller, drives the mechanism. The average load hoisted is 1500 ft. b. m., weighing approximately 12,000 lb. (5443 kg.). The maximum will hardly exceed 6000 ft. b. m., weighing approximately 48,000 lb. (21,772 kg.).

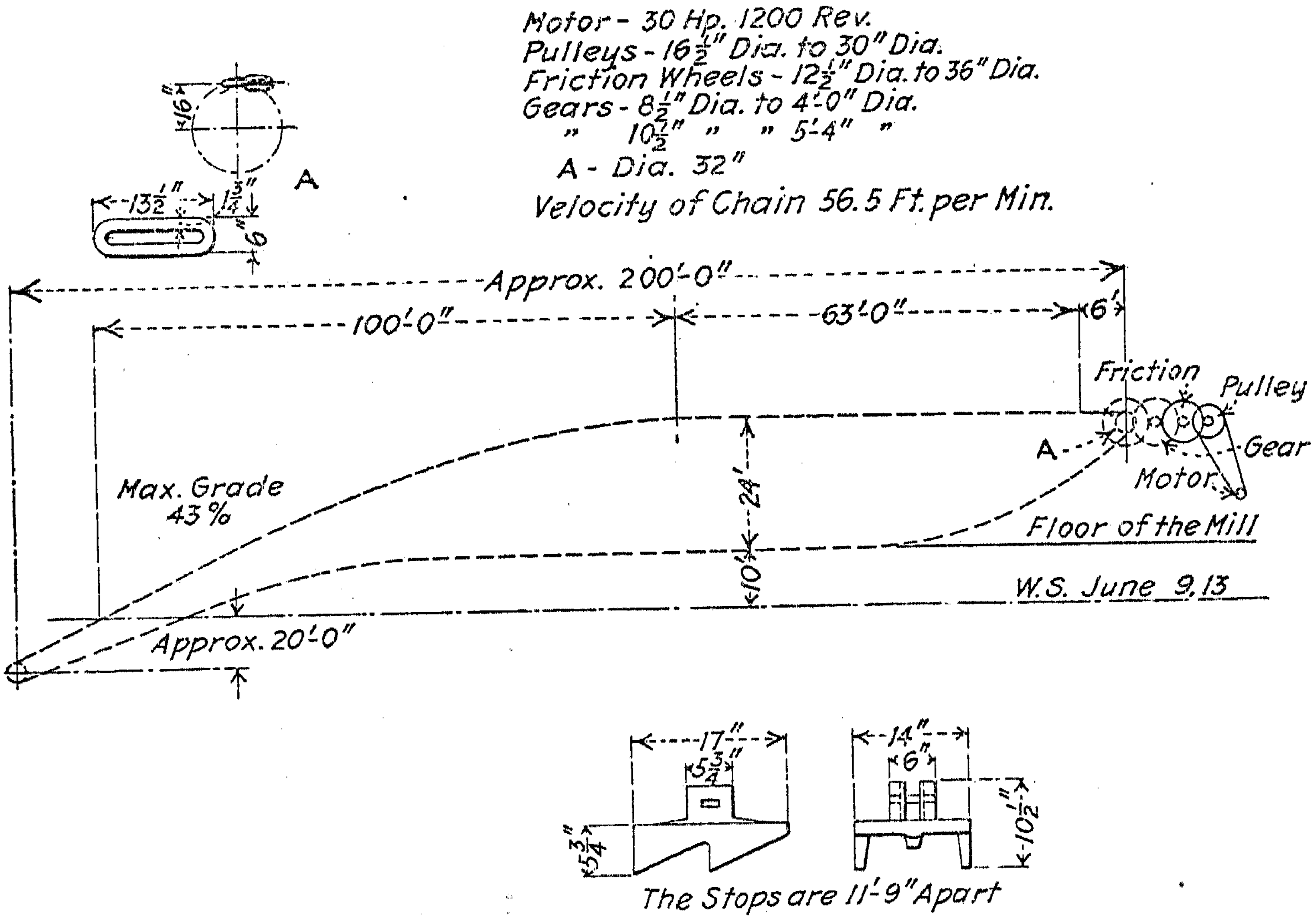


Fig. 13—Log Haul

The rate of hoisting with a maximum load is about 40 ft. (12.1 m.) per minute; length of hoist 10 to 35 ft. (3.05 to 10.76 m.).

Common practise requires 37 to 52 h. p., depending upon the character of the logs handled. The load factor is approximately 6 per cent. See Fig. 14, showing a cross-section of the head end of a sawmill at the head saw.

The adjuncts of a log deck, viz.: "kickers" and "niggers," used for turning the logs and pushing them on the carriage, as well as the log carriage itself, are usually steam-operated. These devices are uneconomical steam users, but their demands are not very great and they are very seldom a source of additional cost in boiler plant capacity.

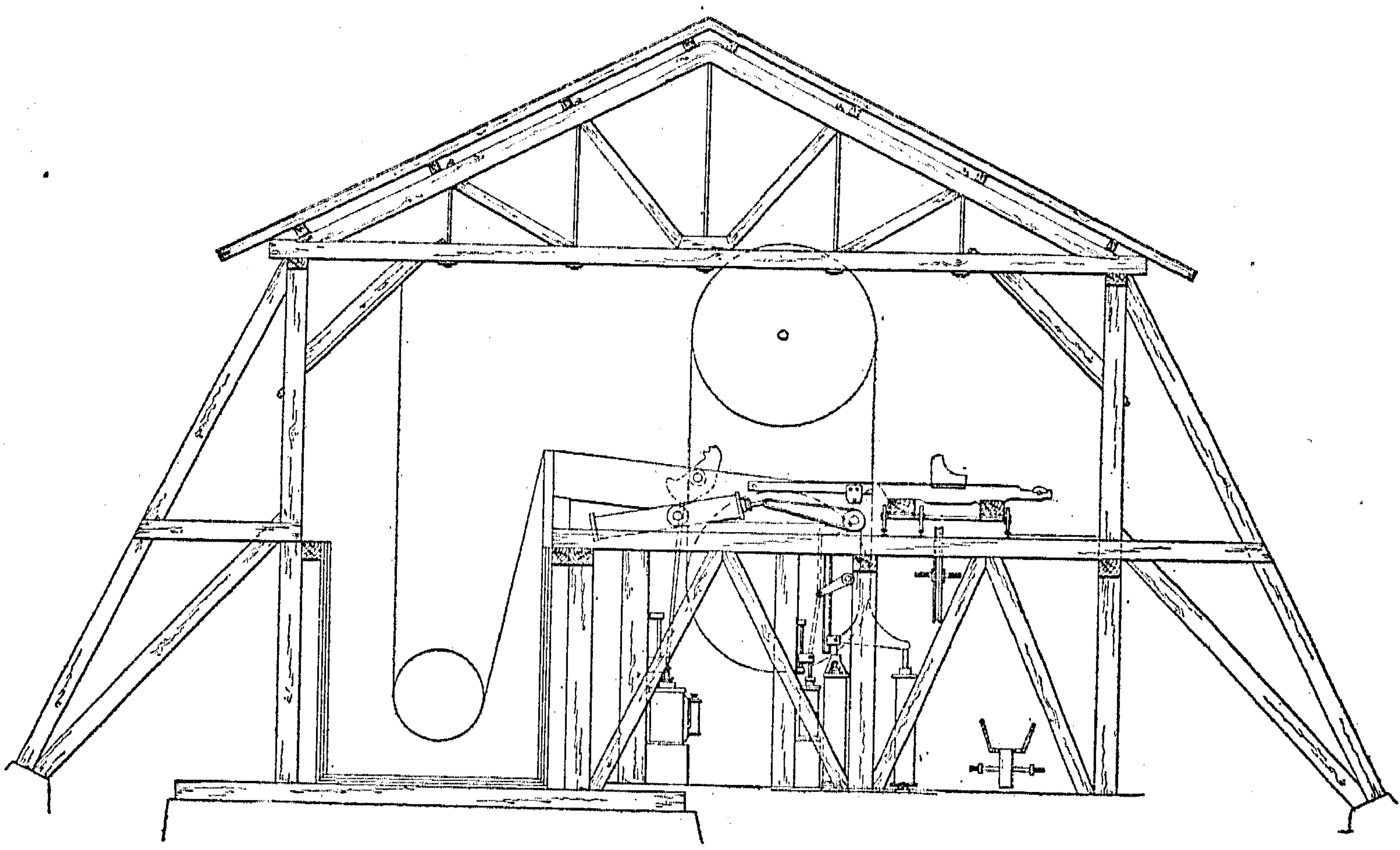


FIG. 14—SECTION AT HEADSAW

The duty of the log carriage, Fig. 15, is very severe, as may be noted from the following typical cycle:

Average speed during cut	250 ft. per min.	(86.25 m.)
" " of return (assuming single cutting mill)	650 " " "	(198.25 m.)
Total distance of travel one direction	20 to 60 ft.	(6.1 to 18.3 m.)
Average weight of carriage and log of 1500 ft. b. m.	38,000 lb.	(17,237 kg.)
Maximum speed during cut	350 ft. per min.	(106.75 m.)
Minimum speed during cut	100 ft. " "	(30.5 m.)

From these we see that the retardation at the end of travel and the acceleration of return must be at very high rates in order to lose a minimum of productive time.

The log after each cut must be moved up a definite amount in preparation for the next cycle. This is accomplished by the set works. A five-h. p. constant-speed induction motor mounted on the carriage and running continuously provides the simplest means of driving this device.

With direct current available, a series motor will prove more economical in energy consumption and will run only when the set works is operating. Current is collected from protected trolleys or from a loop cable supported by rings carried on a rod attached to the side of the building. A back-geared motor or one fitted with silent chain drive proves most compact. The control mechanism must be arranged for reversing operation.

The canting gear, usually driven by a 15-h.p., constant-speed motor, is required only when a very irregularly shaped log is encountered. It consists simply of a drum with attached hook and cable for turning the log on the carriage. This operation is now performed by power machinery in all except the most extreme cases. The motor operates so intermittently that its energy and power requirements are of little interest.

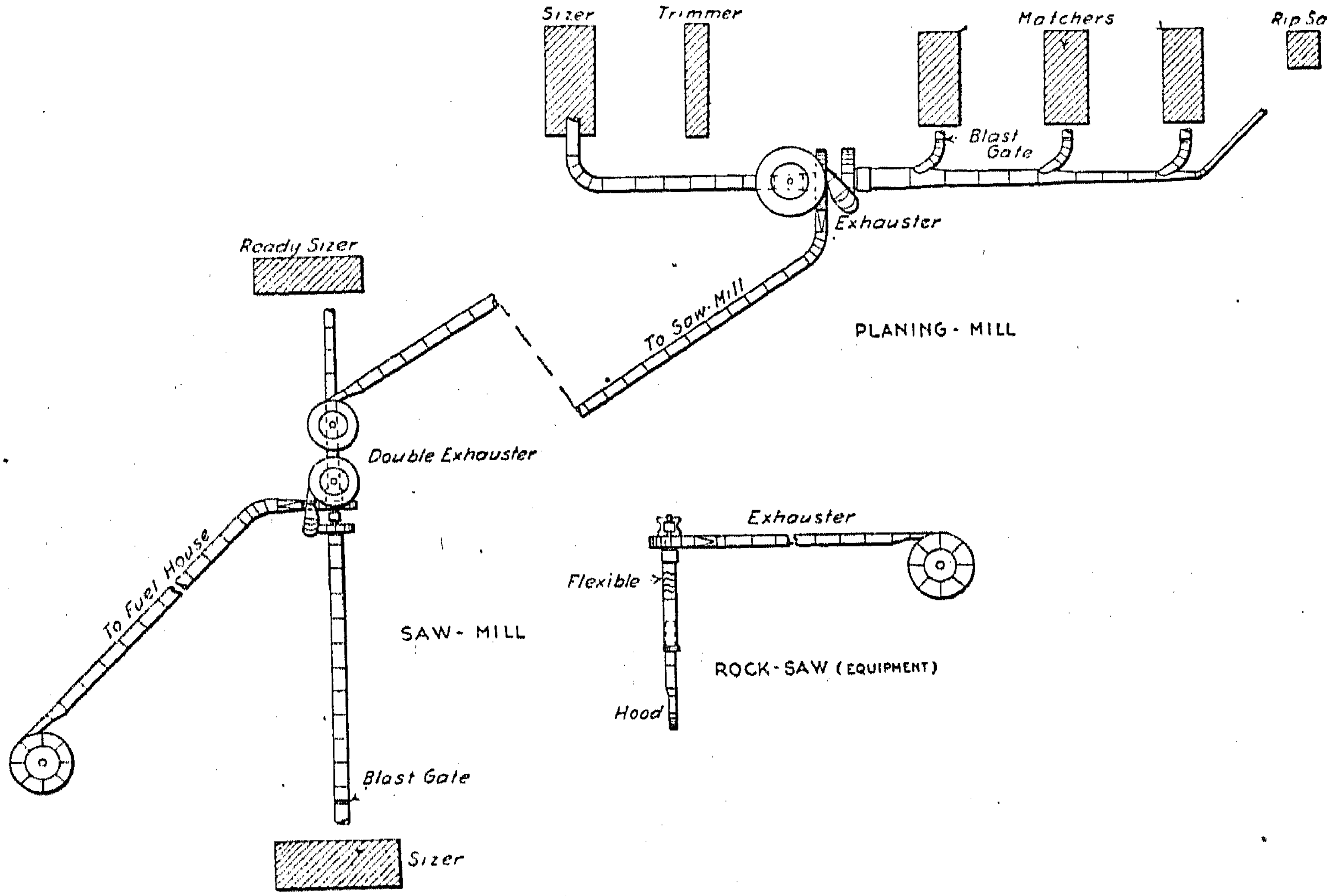
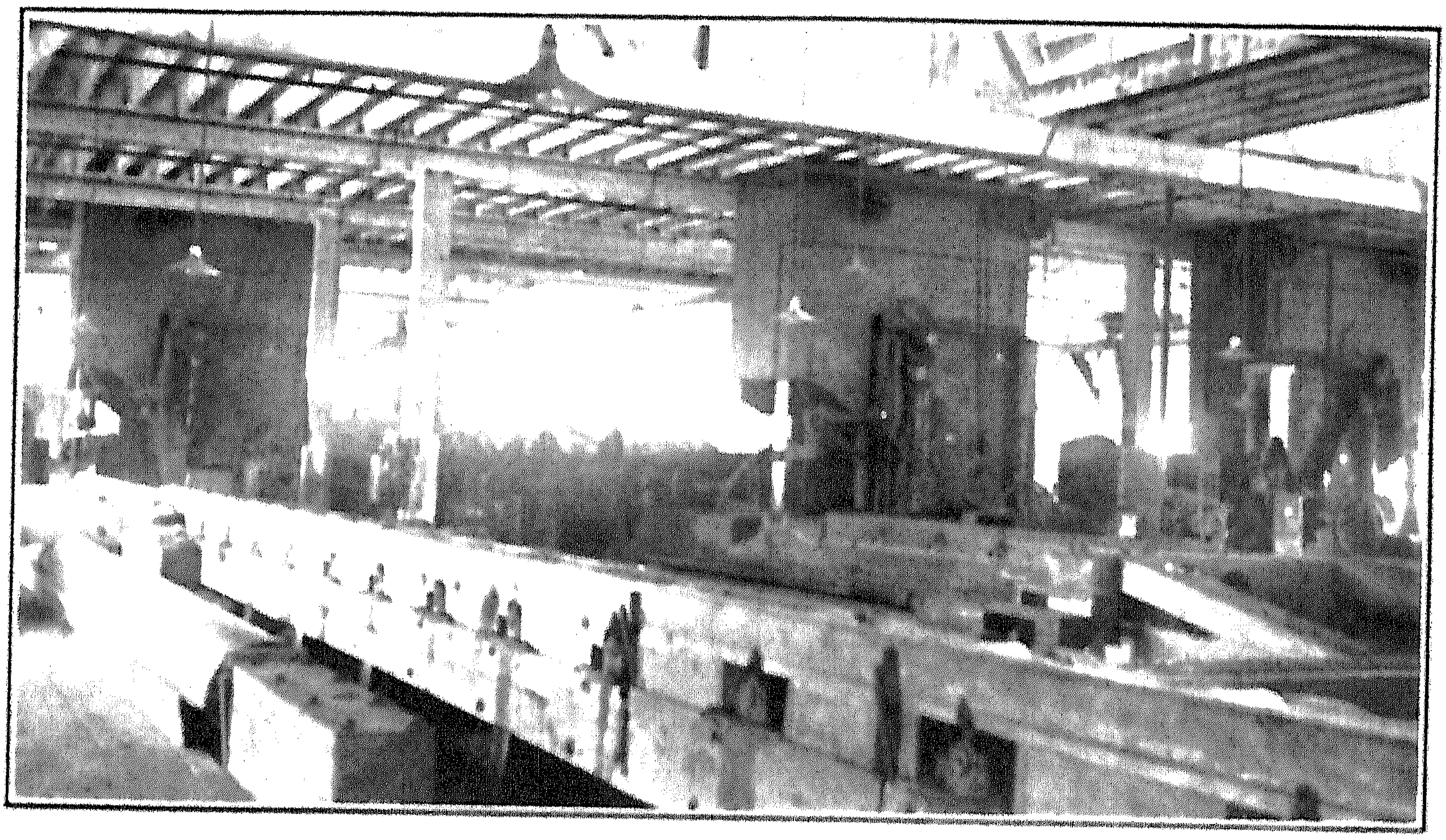


FIG. 16—REFUSE EXHAUST SYSTEM

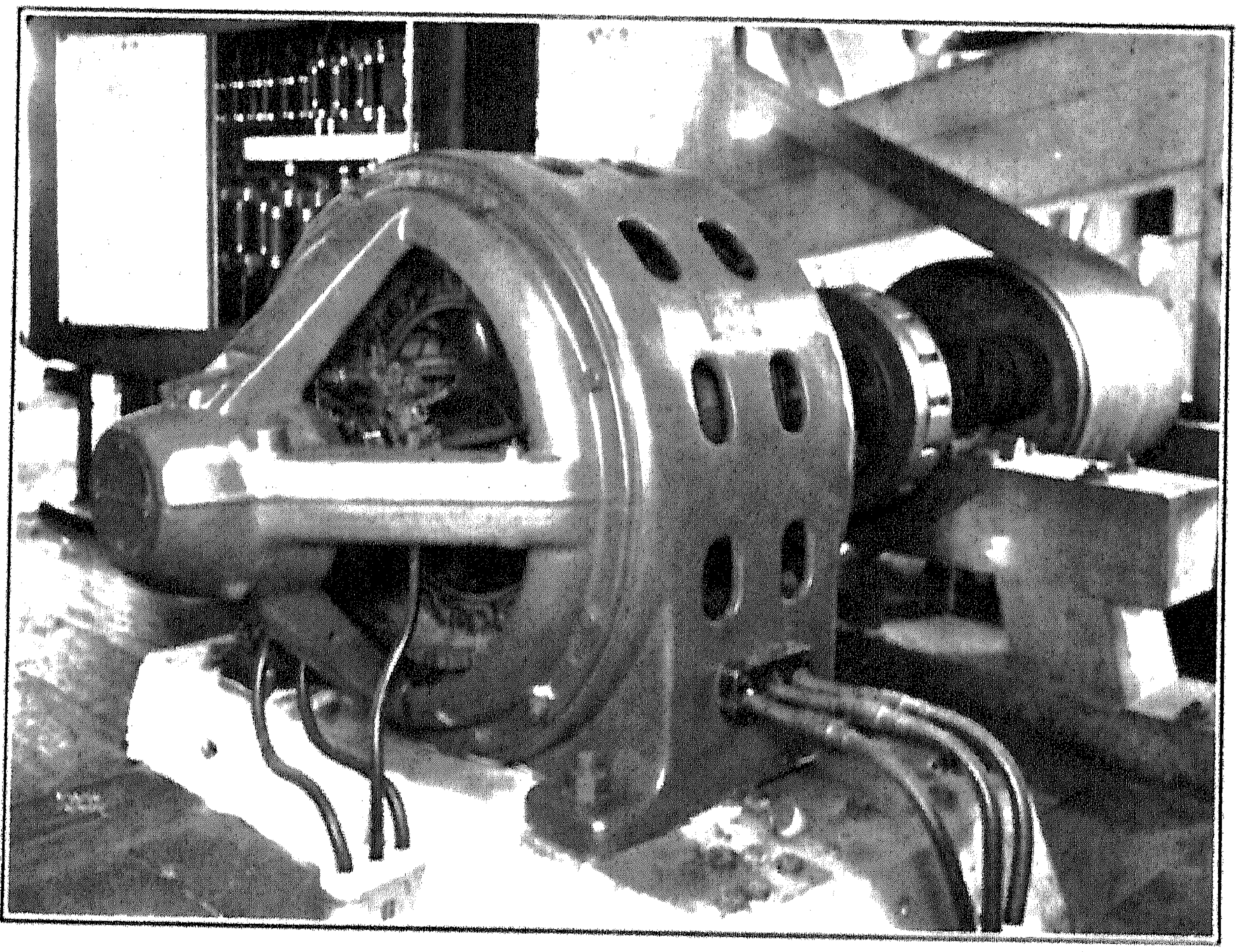
ROCK SAW

A small saw ordinarily known as a "rock" or "barking" saw, to remove gravel, barnacles or other foreign matter from the bark of the log, usually precedes the main saw in the line of cut. It operates continuously, and requires a 15-h.p. motor; its load factor is approximately 30 per cent. A tin housing, piped to an exhaust fan, allows the dust to be carried away. This fan



[WHITNEY]

FIG. 17—MILL FLOOR, SHOWING THREE NINE-FOOT BAND HEADSAWS



[WHITNEY]

FIG. 18—300-H. P. MOTOR DRIVING 10-FT. BAND SAW IN PACIFIC COAST MILL

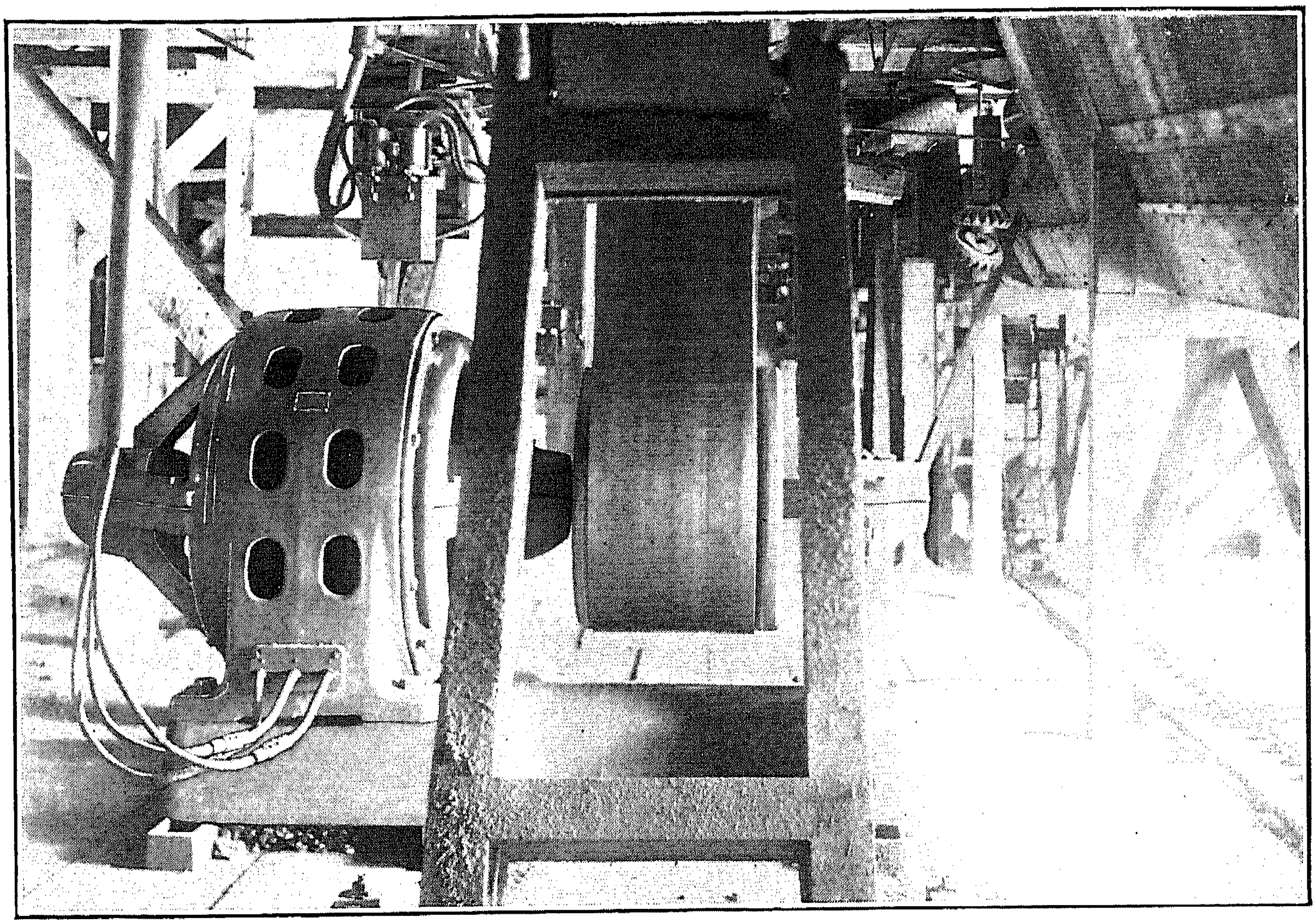


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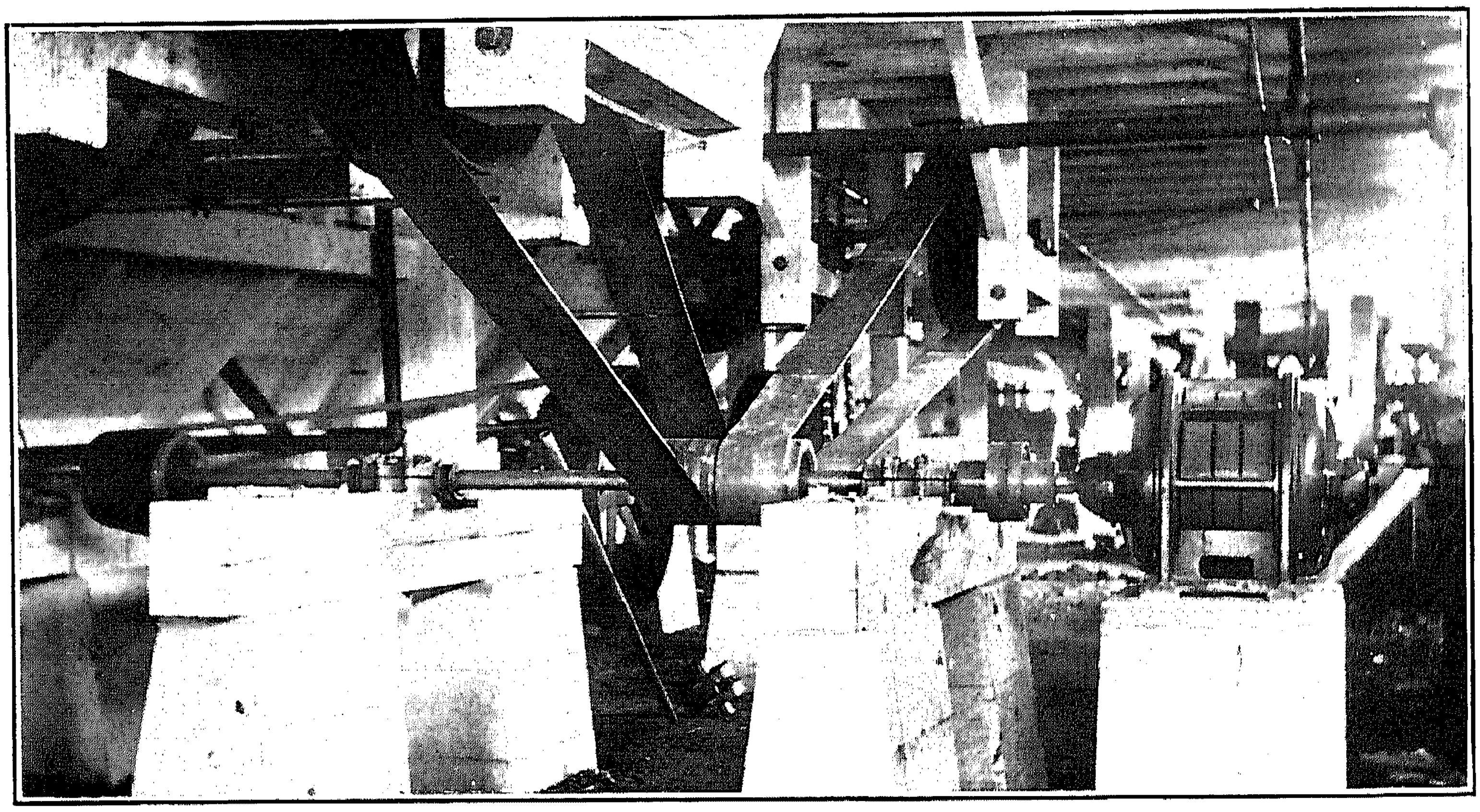
FIG. 19—250-H. P. SQUIRREL CAGE MOTOR DRIVING DOUBLE 66-IN. CIRCULAR HEADSAW IN PACIFIC COAST MILL



[WHITNEY]

FIG. 20—TYPICAL GROUP FOR DRIVING TRANSFERS, LIVE ROLLS, ETC.

requires 15 h.p. and runs continuously at constant speed, with a load factor of approximately 100 per cent. See Fig. 16.

HEAD SAW

The essential duty of this saw is to cut timbers of a certain thickness from the log. Refinements of this process—*i.e.*, reducing these timbers to boards—really fall to other machines, viz., re-saws and gang saws, because of operating requirements. The single-cutting band mill is by far the most popular type of head saw; double-cutting mills are in general use when handling smaller timbers than are common in the Pacific Coast country, but circular head saws are by no means obsolete.

A typical 10-ft. (3.05-m.) single-cutting band mill is shown in Figs. 15 and 17. Driving this is a 300-h.p. constant-speed motor with wound rotor, and provided with drum controller and resistance for starting duty only. The large inertia of the heavy saw tension and driving wheels imposes severe starting conditions, but once up to speed, helps greatly in equalizing the load, so that in running we seldom encounter very high peak demands. The following data are typical of a mill of this capacity:

Speed of saw wheels	300 rev. per. min.
Running demand range	230 to 450 kw. input
Starting demand	560 kw. input
Duration of starting demand	38 seconds
Running light, input	60 to 70 kw.
Average kw-hr. per day of 10 hr.	1050
Load factor—average*	22 per cent

Because of the slow speed of large band mills the motor is usually belted and a belt tightener used. See Fig. 18. Three-bearing motors are universal practise.

The polar wound-rotor type for constant speed service is commonly used, to limit the current input at starting. Where ample station capacity is available a squirrel cage motor can be used with impunity, now that the electrically-welded rotor end-ring construction has so greatly increased its ability to withstand long-sustained starting periods without damage. The simplicity and strength of a squirrel cage type motor makes its use very desirable.

With double-cutting mills the load factor and daily kilowatt-hour consumption are higher than the values given above. The power per thousand feet, however, is lower, due to the greater proportion of working to idle periods.

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*In this instance, as in the others cited, the load factor may not agree exactly with the performance figures given—all figures are averages of a large number of tests and are indicative of average performances only.

CIRCULAR HEAD SAWS

Squirrel cage motors are universally used for circular head saws. The inertia of the circular saws is low and the load fluctuations during the cut must be taken care of entirely by the motor. Fig. 19 shows a motor driving a double circular 66-in. (1.68-m.) saw. Where the saw speed permits, the best practise is to connect the motor directly to the lower saw arbor, driving the top saw with a belt. The following operating data are typical of a large double circular head saw:

Running demand range	240 kw. to 560 kw. input
Starting demand	360 kw. input
Duration of starting period	15 seconds
Running light	35 kw.
Average kw-hr. per day of 10 hr.	1150
Load factor, average	20 per cent

From the head saw, the boards or cants are conveyed by rolls and transfer chains which distribute the product to the other machines (Fig. 20). The rolls directly in front of the head saw run at speeds of about 350 ft. (106.7 m.) per minute, the speeds in later sections decreasing slightly.

Present practise leans toward grouping two sections of roll with one or more sets of transfer chain, driving the group from a countershaft operating at 900 rev. per min., and driven by a direct-connected, constant-speed, squirrel cage motor. All rolls must be arranged for both forward and reverse operation, and the simplest scheme for accomplishing this and at the same time relieving the motor of all starting demands, requires the use of friction devices.

With individual motor drive, a back-geared reversing motor with chain drive from the back-geared shaft provides the most compact arrangement. Such a motor should preferably be of the polar-wound rotor type. Fig. 21 shows a general scheme using group drives.

Live rolls 12 in. (30.48 cm.) diameter by 30 in. (76.2 cm.) long require approximately 0.4 h.p. per roll when operating at 200 rev. per min. When operating at 100 rev. per min. they require approximately $\frac{1}{4}$ h.p. per roll. As a typical group, a section containing eighteen 12-in. by 30-in. (30.48 by 76.2-cm.) rolls at 120 rev. per min. and thirteen 12-in. by 30-in. (30.48 by 76.2-cm.) rolls at 80 rev. per min., three slab transfer chains, and three edger transfer chains, requires seven kw. input.

As an example of individual motor drive, with back-geared motor and chain drive to one roll case containing fifteen 12-in.

by 32-in. (30.48 by 76.2-cm.) rolls driven from a line shaft by bevel gearing, the maximum running load is 4.8 kw. and the average running load is 3.7 kw. This information applies to cases where rolls are well lubricated and gearing in first-class shape. No average conditions can apply generally, since by far the greater part of the load is due to friction.

EDGER

The function of this machine is to cut the stock to width after it has been cut to a predetermined thickness by the head saw. It therefore consists of a number of circular rip saws, with the position of each adjustable on an arbor, the total width of stock determining the number of saws working at any one time and their position. See Fig. 22. Edgers adapt themselves admirably to direct connection; their speed is high and saw sizes can be so chosen as nicely to fit a 1200- or 1800-rev. per min. motor, which speeds are suitable for direct connection.

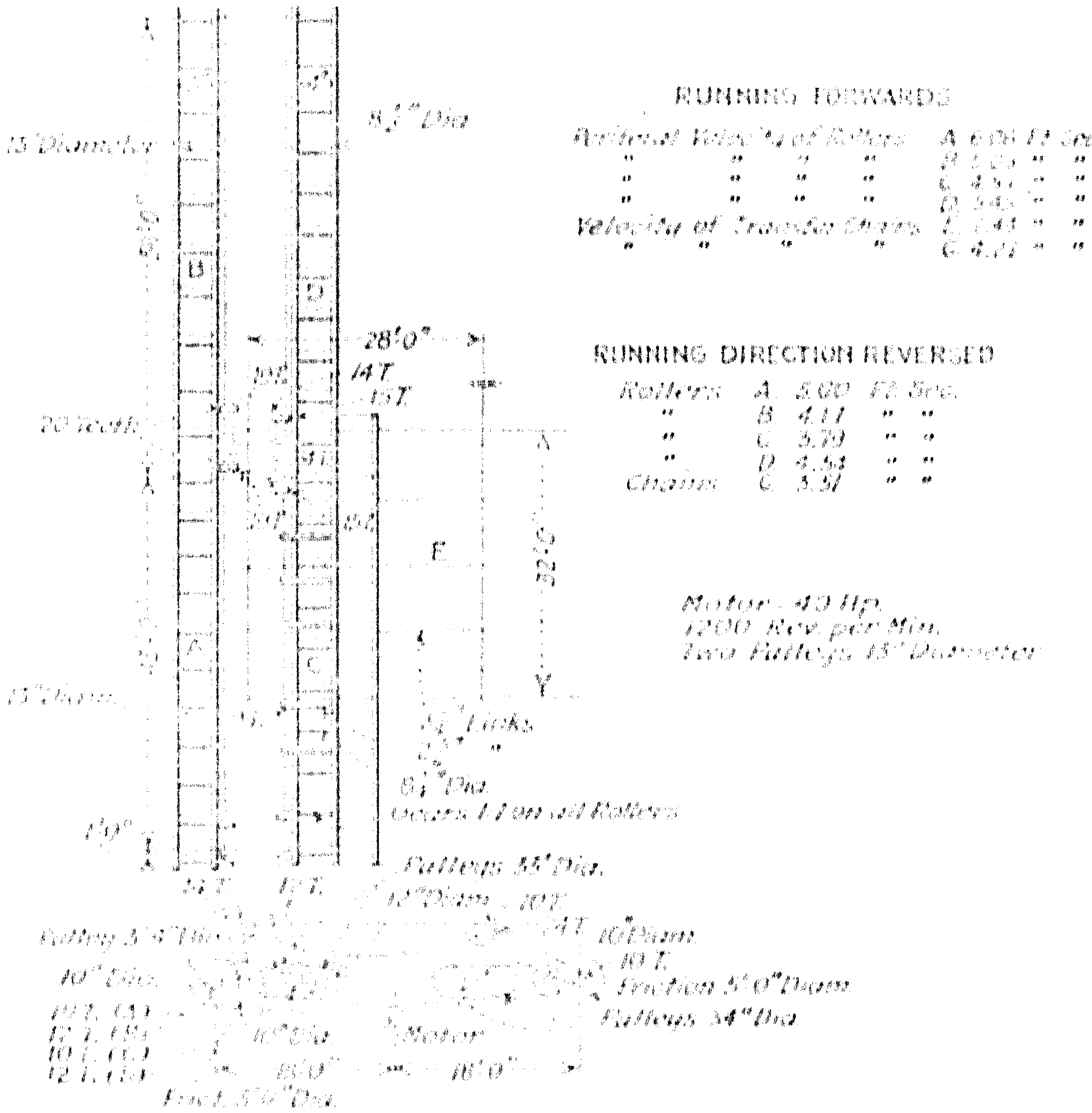


FIG. 21.—GROUPING OF LIVE ROLLS AND CHAINS DRIVEN BY ONE MOTOR

The starting load is comparatively light; the running load fluctuates through wide ranges and the saw speed should be practically constant, which conditions have caused the squirrel cage, constant-speed induction motor to be universally adopted. The feed rolls should be reversible, and capable of having their speed adjusted (see Fig. 23), the rate of feed depending upon the stock and varying from 325 ft. (99.1 m.) per minute to 120 ft. (36.6 m.) per min. For driving these rolls the latest practise has adopted a varying-speed, constant duty, reversing motor with polar-wound rotor.

On the edger arbor are mounted from five to seven saws running at rim speeds of 9000 to 12,000 ft. per minute. The following is typical of the demands of a Pacific Coast edger 12 in. by 72 in., eight saws direct-connected to a 200-h. p. 1200-rev. per min. squirrel cage type motor:

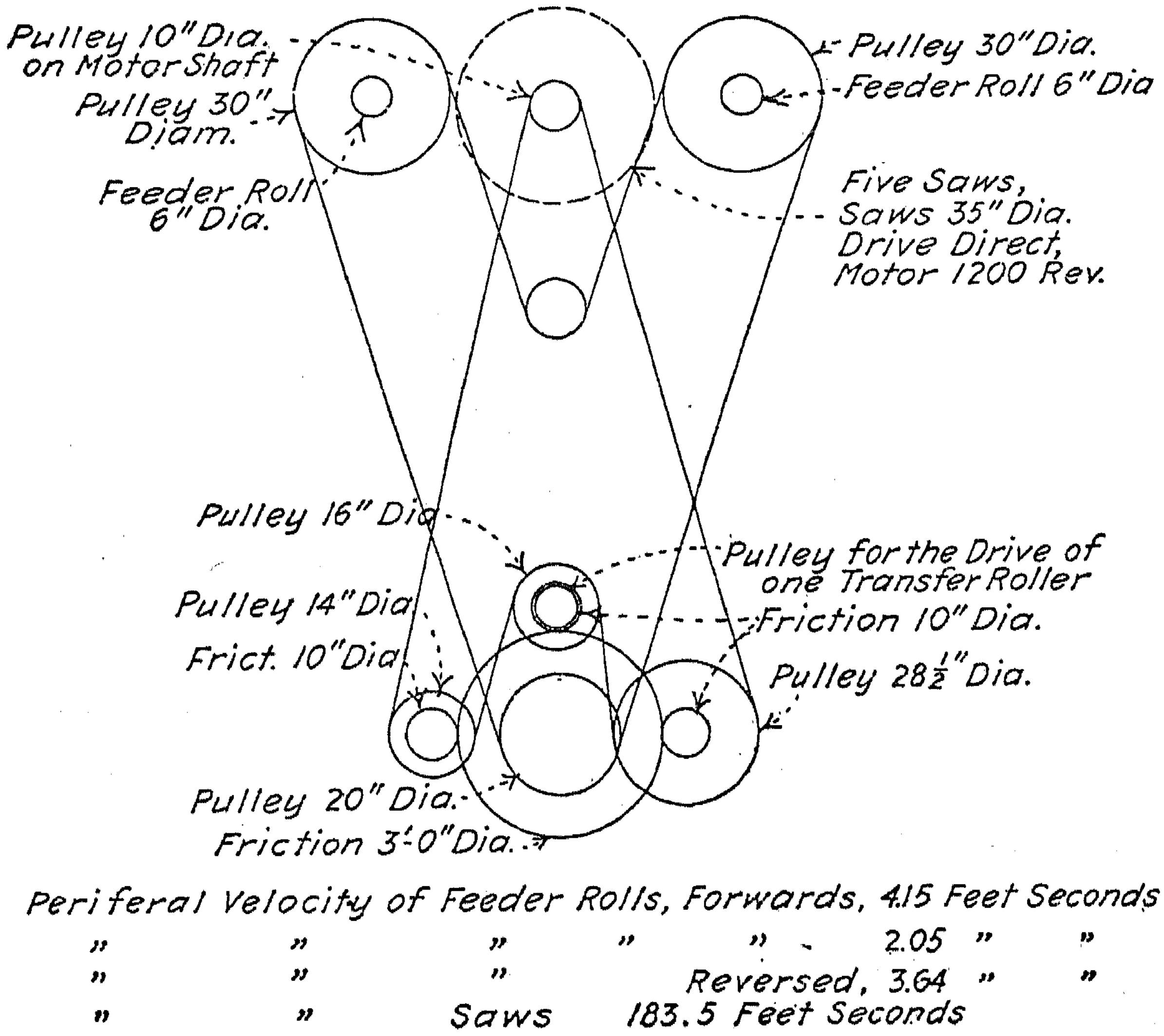
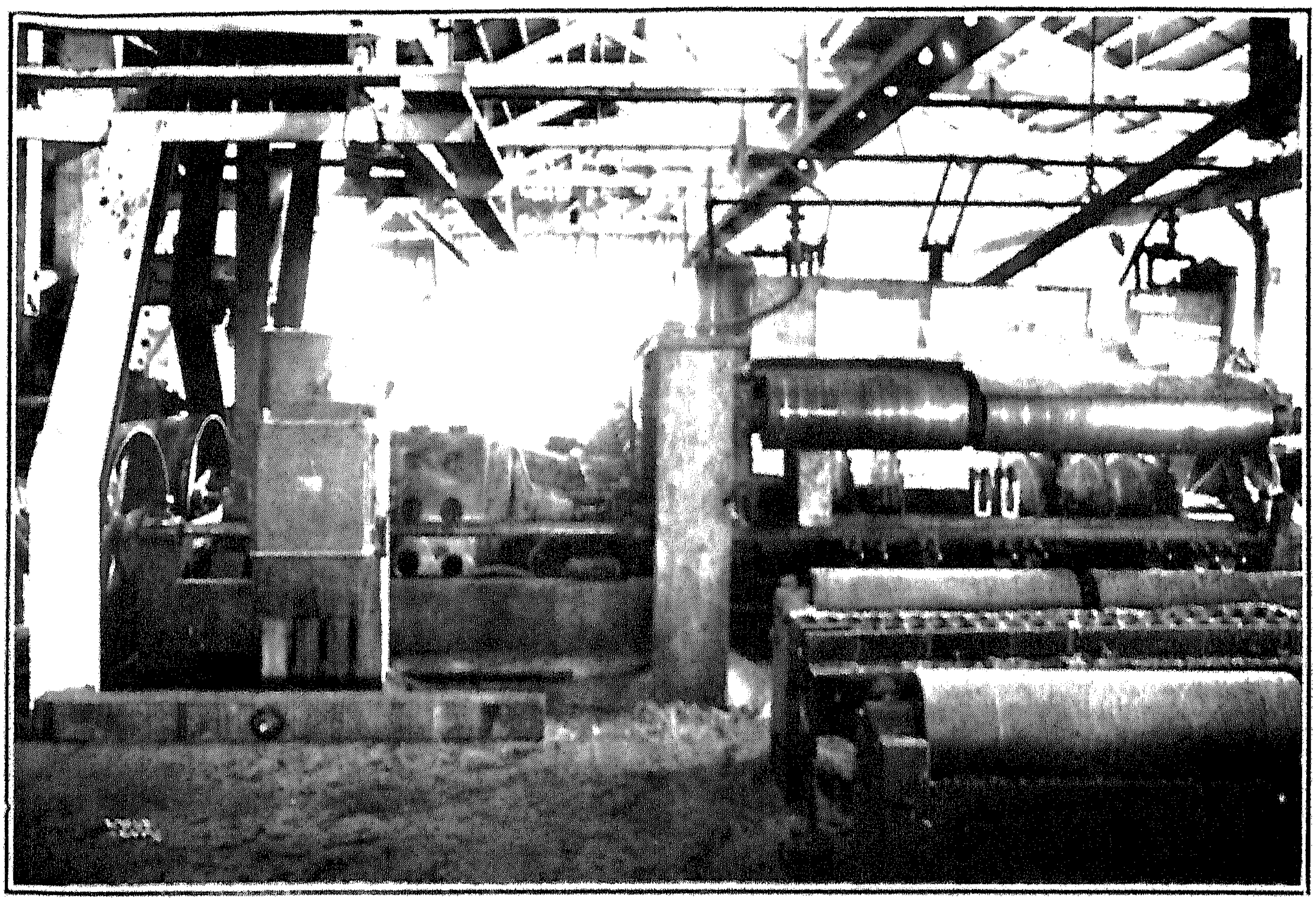


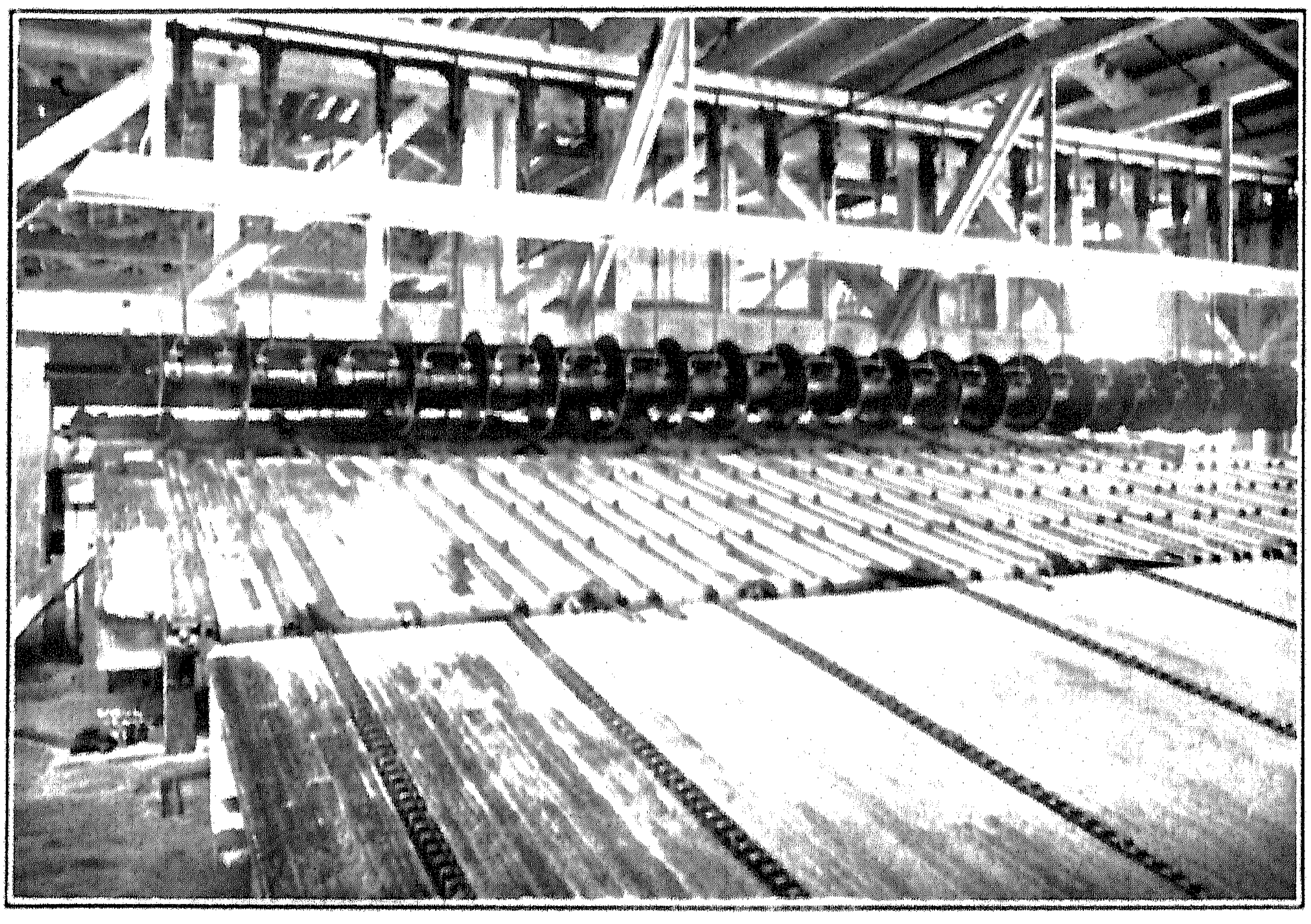
FIG. 23—FEEDER ROLL DRIVE

Input—idle	35 kw.
—5 saws cutting 6 in. stock @ 220 ft. per min.	350 "
—5 saws cutting 6 in. stock @ 135 ft. per min.	247 "
—3 saws cutting 10 in. stock @ 135 ft. per min.	290 "
—4 saws cutting 2 in. stock @ 230 ft. per min.	75 "
—6 saws cutting 1½ in. stock @ 240 ft. per min.	75 "
Average per 10-hr. day	405 kw-hr.
" load factor	11.6 per cent.



[WHITNEY]

FIG. 22—200-H. P. MOTOR DIRECT-CONNECTED TO 12¼ BY 84 IN. EDGER HAVING EIGHT SAWS



[WHITNEY]

FIG. 25—FRONT OF 40-FT. TRIMMER REQUIRING A 50-H. P. MOTOR

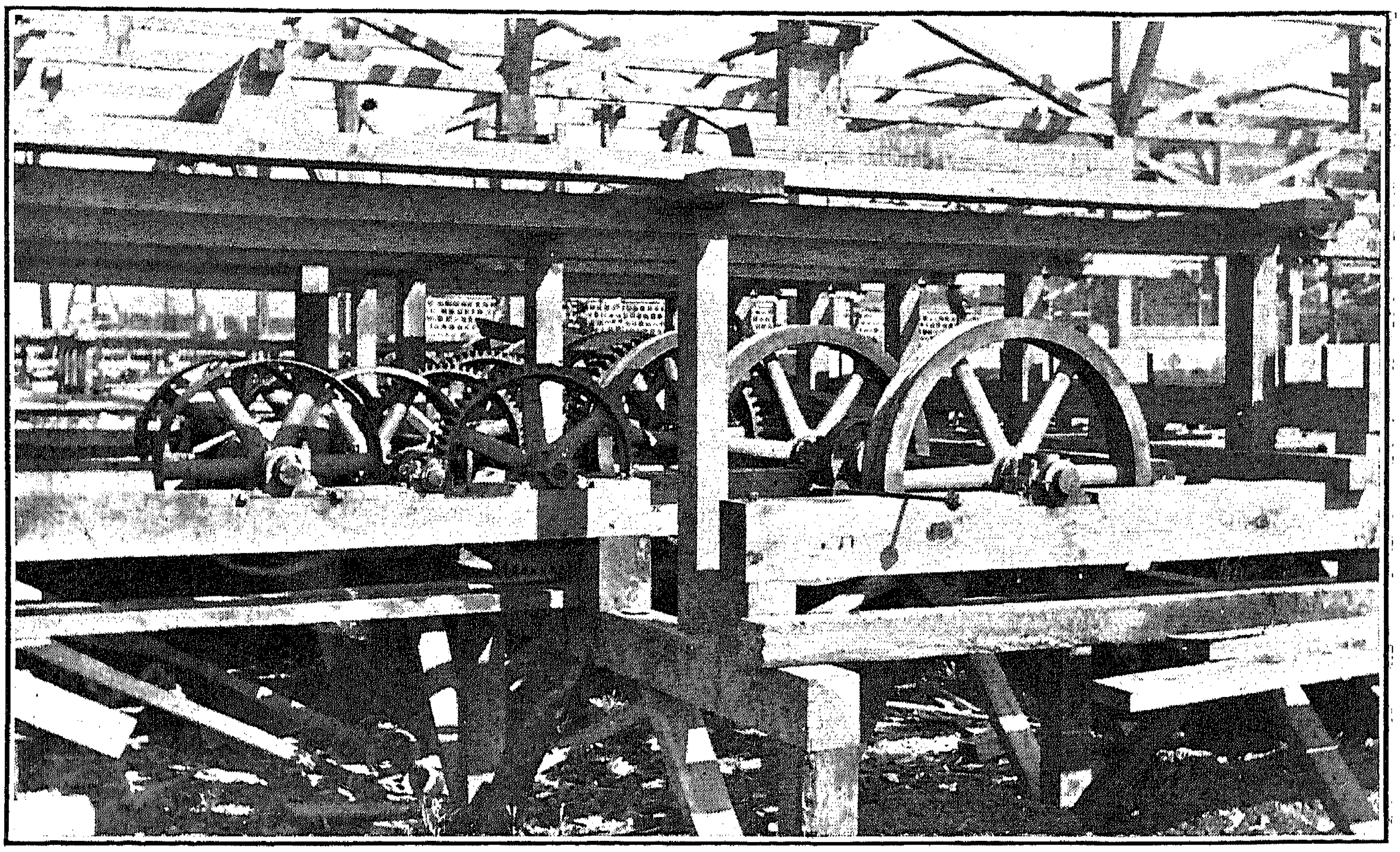


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FIG. 27—TRANSMISSION FOR SORTING TABLE. DRIVE RATIO 900 TO 1

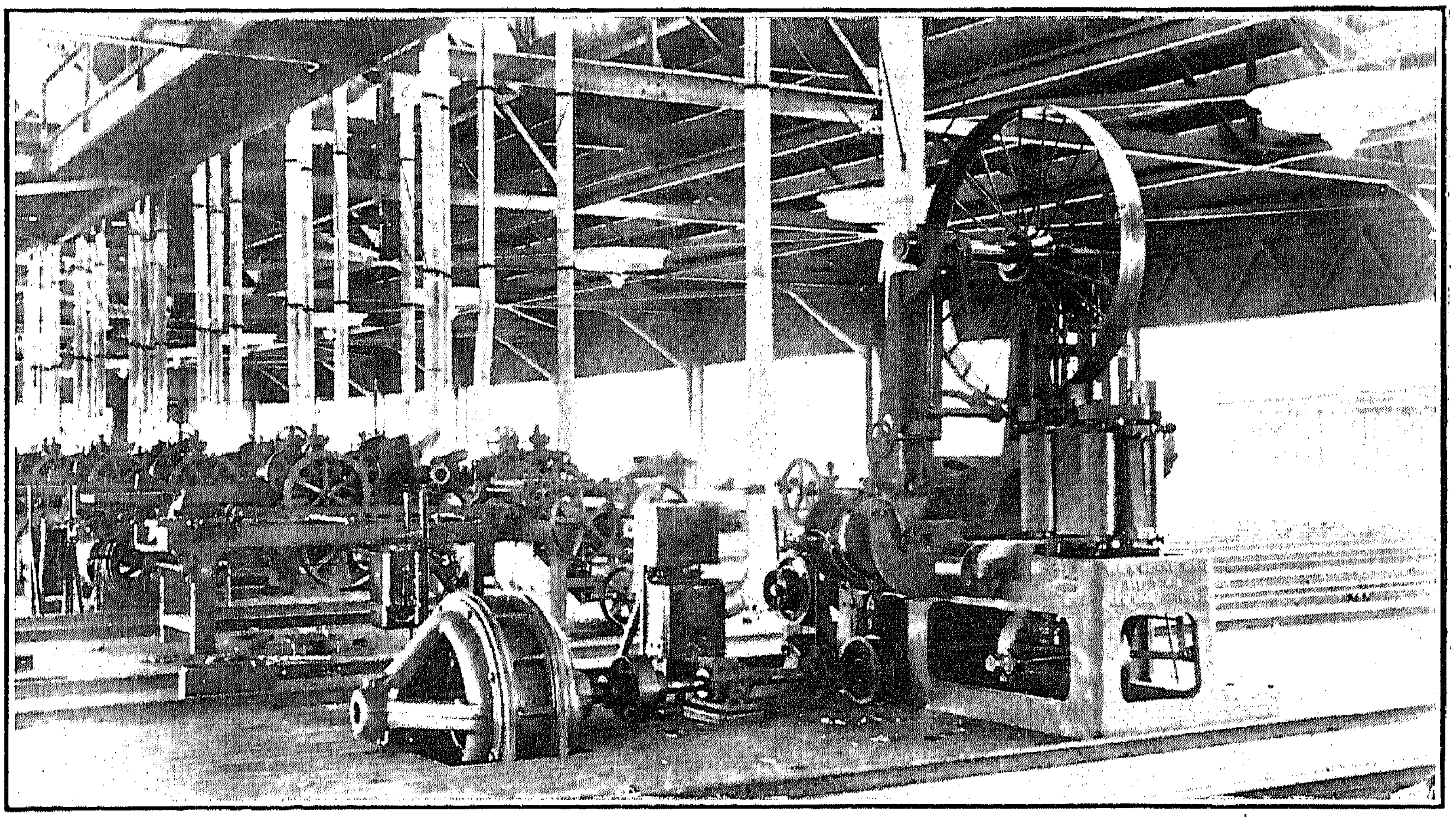


FIG. 28—BAND RE-SAW WITH DIRECT-CONNECTED MOTOR [WHITNEY]

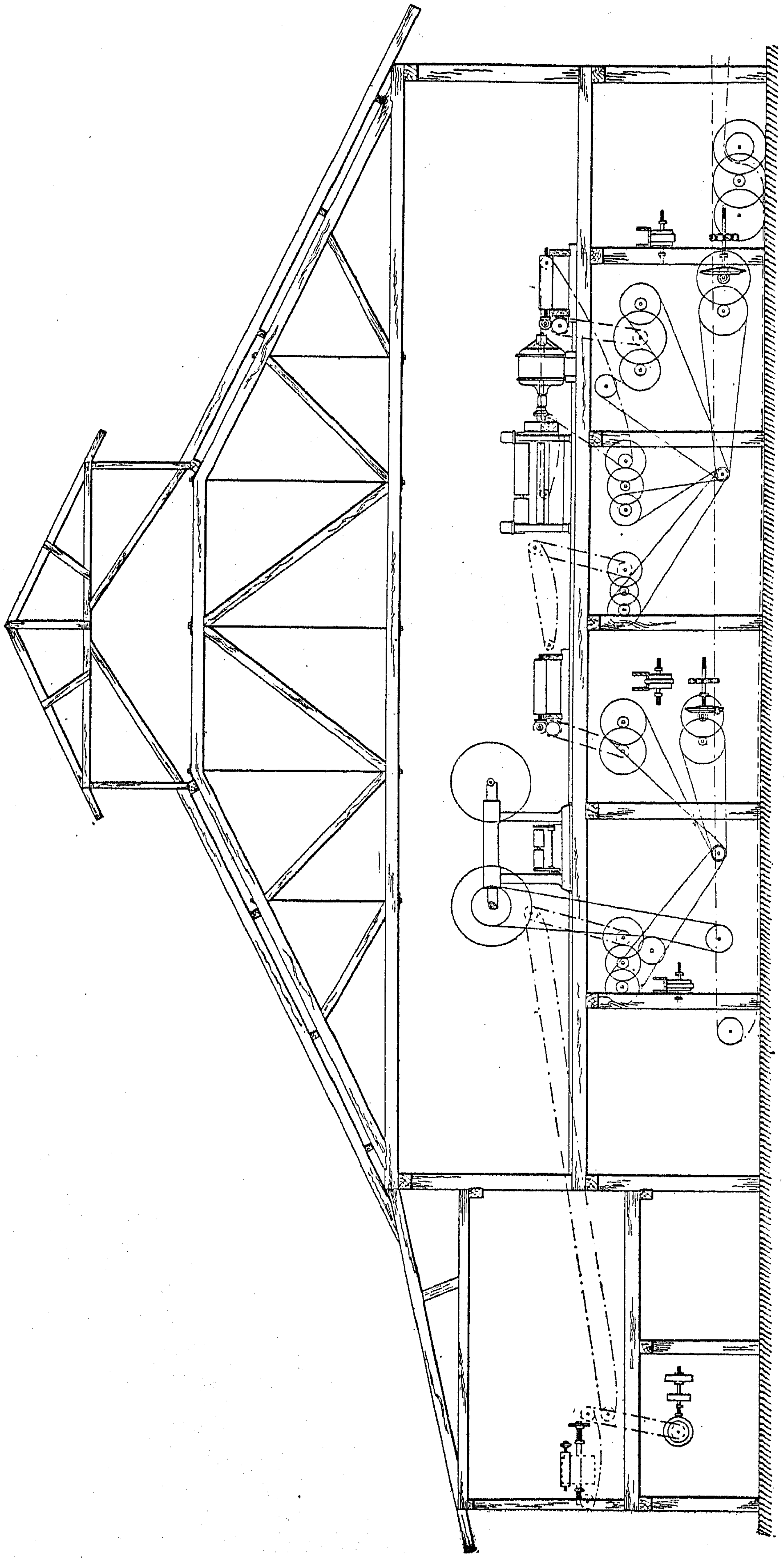
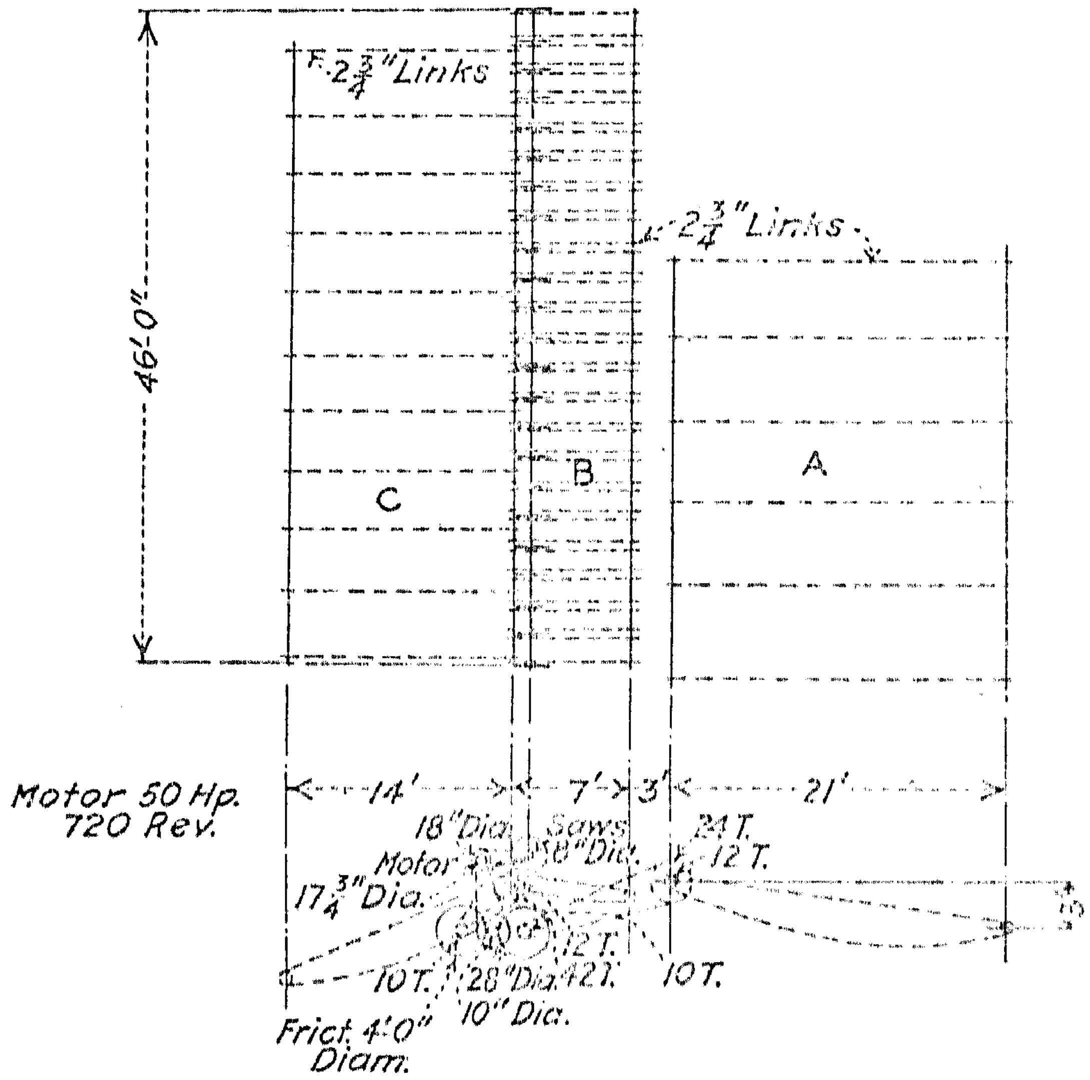


FIG. 24—SECTION AT EDGER AND RE-SAW

TRIMMER

This appliance cuts rough stock to length. It consists of a gang of circular saws arranged in a horizontal line and spaced two feet apart, the total length varying from 40 to 50 ft. (12.2 to 15.25 m.). See Figs. 25 and 26. There are rarely more than four or five saws working at any one time and the load demand lasts only for an instant, so that by far the greater part of the energy is consumed in running the saws idle. The speed of the saws is of course constant, and operating constantly the load factor is 60 to 70 per cent. The saws are belted to a main drive shaft which in turn is driven by a direct-connected, constant-speed squirrel cage motor. For average conditions, 50 h.p. suffices. The following observations give the operating requirements including transfer mechanism:



Saws 30" Dia. and Periferal Velocity 212 Feet Seconds
Velocity of Transfer Chains A. 109 Feet Minute
" " " " B. 62.2 " "
" " " " C. 62.2 " "

FIG. 26—TRIMMER

Running demand range when cutting	47 to 80 kw.
Starting demand	70 kw. input.
Duration of starting	18 seconds
Running light, input	29 kw.

SORTING TABLE

From the trimmers, the stock passes over chain conveyers spaced 4 ft. (1.22 m.) apart, to the sorting table, where it is graded and removed for placing in yard stock, treating in the dry kilns preparatory to further finishing, or to be returned to the mill for further reworking.

The sorting table consists of several chains or cables running at about 15 to 30 ft. (4.58 to 9.15 m.) per minute. The starting requirements are heavy, since the mass to be accelerated is very large. A friction device is invariably placed in the speed-reducing transmission machinery, however, which relieves the motor from all starting strains and allows a squirrel cage type motor to be used for the drive.

The motor is semi-exposed to the weather, and in its manufacture, this fact should be considered. The running load is fairly light and practically constant. A motor with polar-wound rotor, back-geared shaft and chain drive from back-geared shaft direct to table driving sprocket, will eliminate all of the transmission machinery shown in Fig. 27. This scheme has not met with general success, however, due to the very severe starting strains as compared with the running load. The table itself should be of such length that sorting for both dimensions and lengths can be accomplished without too great congestion at its end. The power requirements for an average case are about as follows:

Motor, 10 h. p. back-geared 850 to 128 rev. per min.
Chain drive from back-geared shaft.
Drives 1706 ft. No. 75 chain—Chain weight 3445 lb.
Lumber per hour = 12,000 ft. b. m.
Speed of first section 35 ft. per min.—decreasing to 29 ft. on last section.
Maximum noted load running .... 7.5 kw.
Average load running .... 5 "

RE SAWS

These machines re-work stock which has not been cut to its ultimate thickness at the first operation. Fig. 28 shows a six-inch vertical re-saw which is direct-connected to a 75-h.p. motor. The starting duty is heavy, due to the weight of the lower wheel and the inertia to be overcome. It is therefore common practise to use a squirrel cage motor with substantial end-ring construction and resistance rotor. When running, the tension wheels serve as an equalizer, reducing the peak demands. The feed rolls are sometimes operated by an individual motor, and in a re-saw of this size, approximately 10 h.p. is required for them, the feed roll motor being a standard squirrel cage machine.

The following are typical service data of a heavy-duty band re-saw:

Rate of feed	185 ft. (56.4 m.) per min.
Splitting, 2 in. (5.08-cm.) by 12 in. (30.48 cm.)	80 kw. input
4 in. (10.16 cm) by 10 in. (25.4-cm)	60 " "
Running light	16 " "

Horizontal re-saws are becoming more popular because of the ease with which they may be instantly adjusted to care for stock of different dimensions. Such a machine can, for instance, handle on one side of its adjustable bed a 6 in. by 12 in. cant, re-sawing to 4 in. by 12 in. and 2 in. by 12 in., and on the other side at the same time re-work a 2 in. by 8 in., making two 1 in. by 8 in. boards. The starting duty is about the same as for the vertical type. The running load fluctuates no more widely.

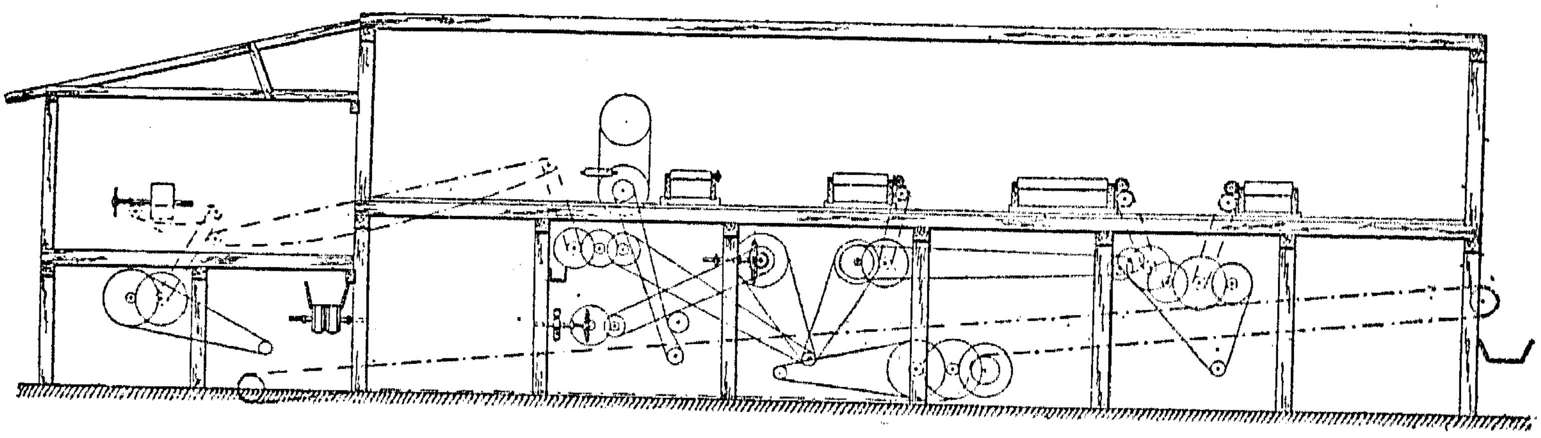


FIG. 31—SECTION OF RIPSAW

GANG SAWS

Gang saws, as the name implies, consist of a number of straight crosscut saws which split a cant at one operation into a great number of boards of the proper thickness. The boards then proceed to the trimmer and are cut to length, as with the output of the edger. These saws have a vertical reciprocating and oscillating motion and the machine is equipped with a flywheel to equalize the load. The average size gang requires a 75-h.p. motor.

A rip saw, Figs. 29 and 30, is required to reduce the width of a certain amount of the mill run, according to order demands. Fig. 31 shows a rip saw, rolls and transfer to rip saw from first section of sorter chains. A silent chain drive or a direct-connected motor may be used. Either method operates satisfactorily, the particular drive adopted depending on the mill layout and space available.

Rough timbers often require no further sizing work than can be performed by the head saw, and never more than an additional passage through the edger. They are conveyed directly to the

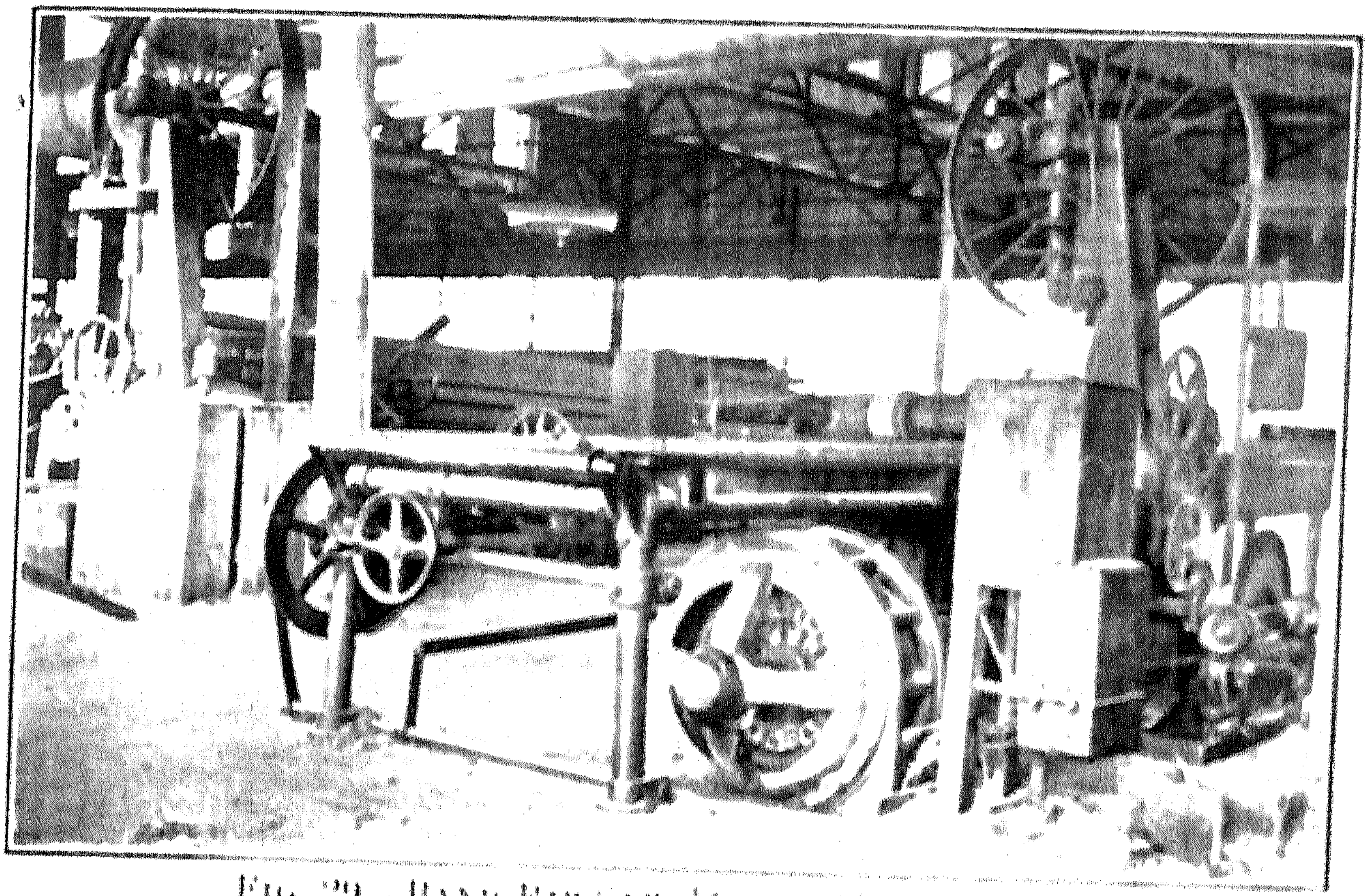
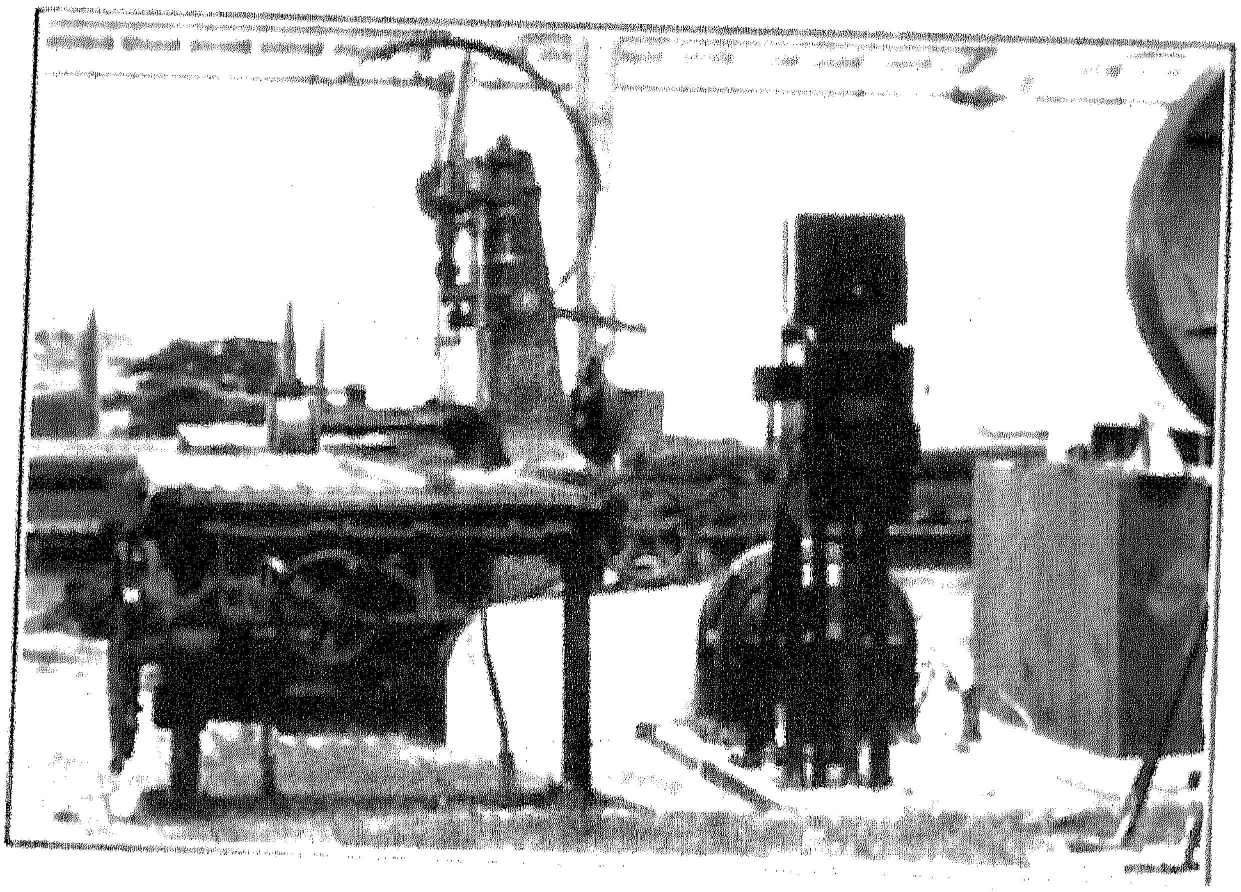
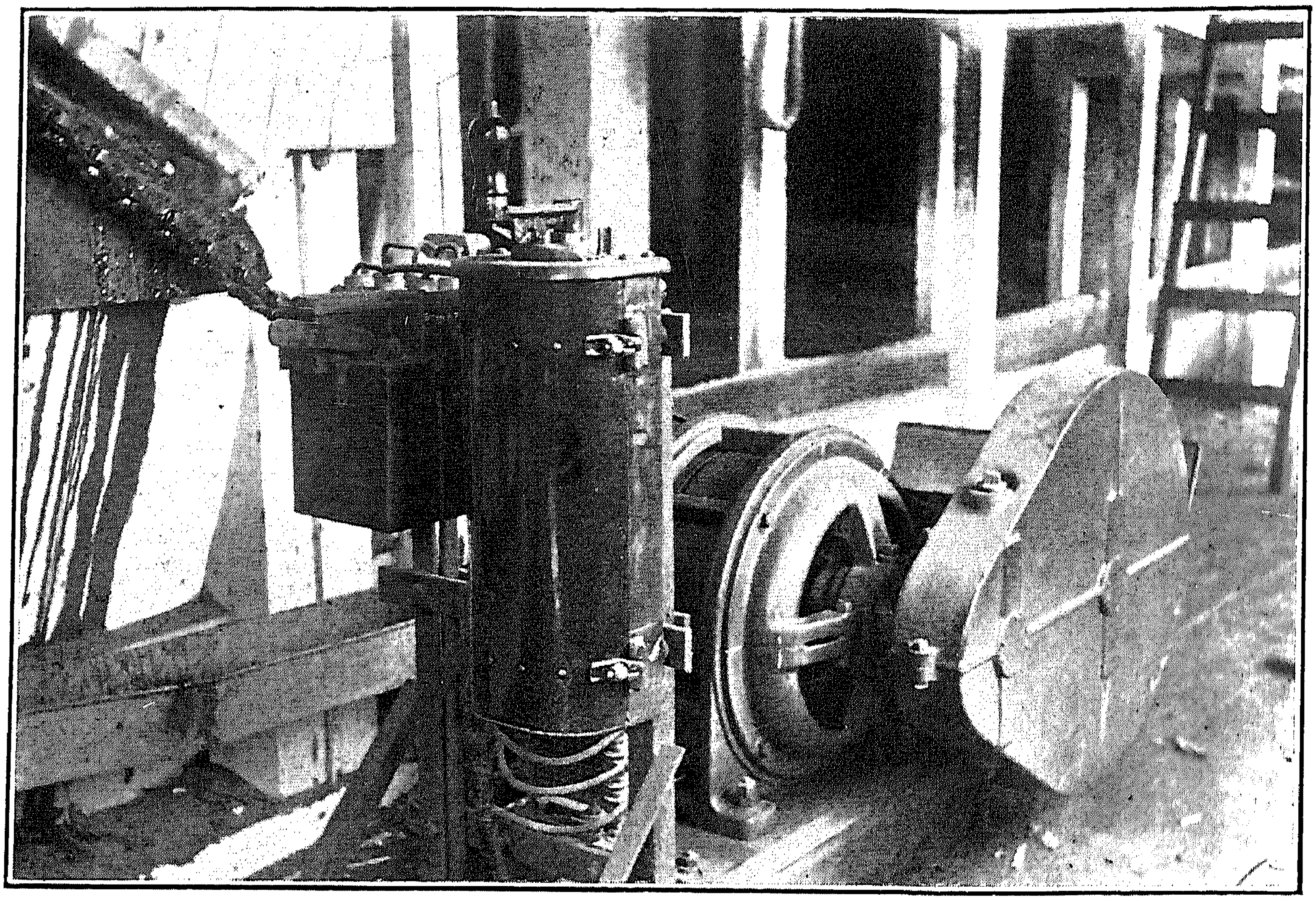


FIG. 29—BAND RIP SAW DIRECT CONNECTED TO MOTOR. LARGE RE-SAW IN DISTANCE [illegible]

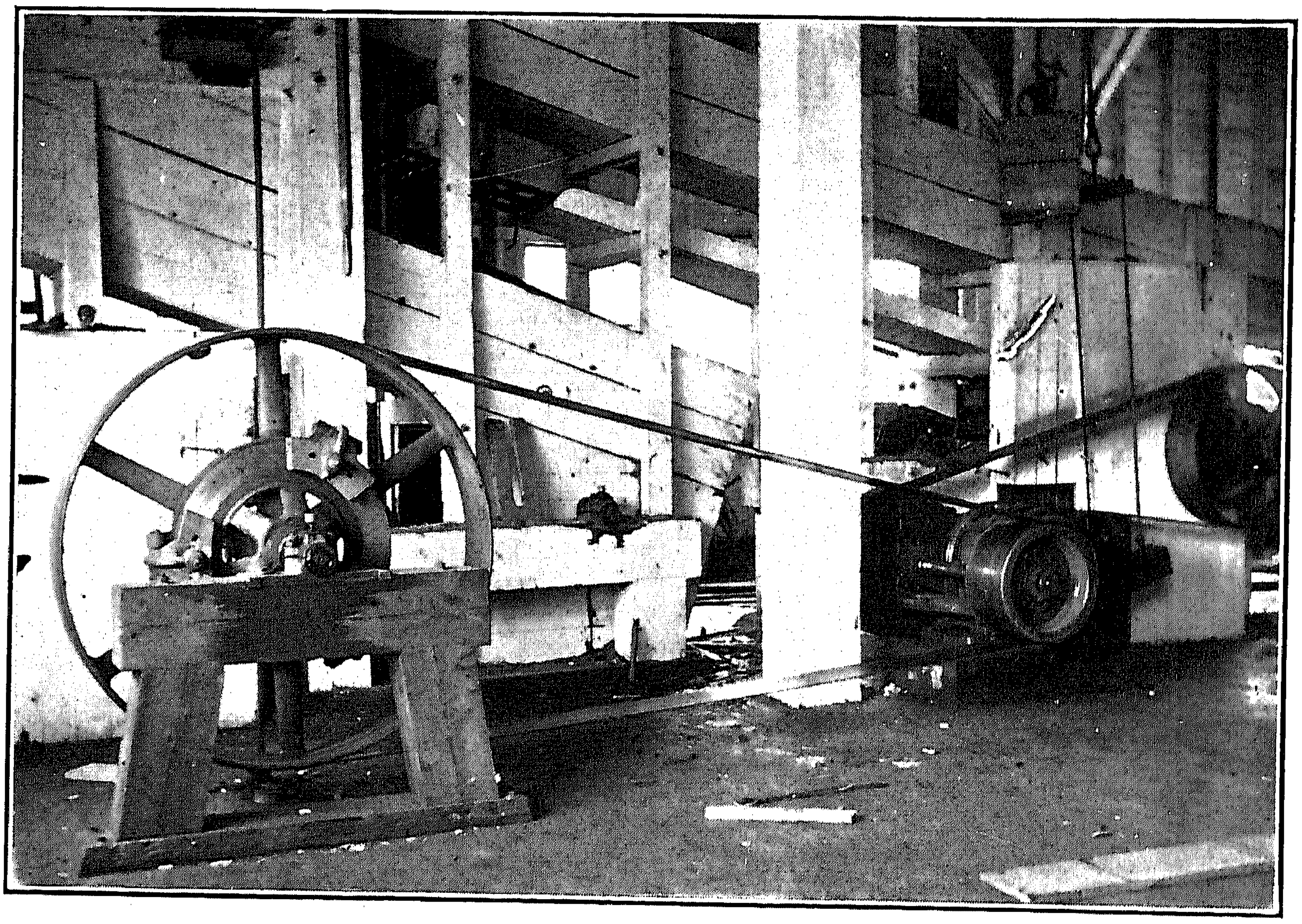


[illegible]

FIG. 30—BAND RIP SAW DRIVEN BY SILENT CHAIN



[WHITNEY]
FIG. 33—BACK-GEARED MOTOR OPERATING CONVEYER



[WHITNEY]
FIG. 34—BACK-GEARED MOTOR BELTED TO BURNER CONVEYER

tail end of the mill, where the ends are squared by a large crosscut saw—and then proceed to the loading platform. Sometimes, however, for uniformity of alignment in building operations, one or more sides must be planed after the timbers have been squared at the end, and consequently they go to what is known as the "green" mill. This consists of one or more planing machines, with an exhaust fan to dispose of the shavings. The planers ordinarily used for this work are known as "ready sizers," a machine which is quickly adjustable for different size timbers and is arranged to surface only an edge and a side, and "timber sizers," which ordinarily have four cutting heads and can surface all four sides of the stock. The average power requirements of such a machine are as follows:

TIMBER SIZER

Size stock	Feed	Sides sized	Input Kw.
5 in. by 5 in.	60 ft. per min.	4 sides	Avg. 33.2 Max. 41.1 Min. 29.1
2 by 12 in.	125 ft. " "	4 sides	Avg. 46.2 Max 71. Min. 43.

READY SIZER

Size stock	Feed	Sides sized.	Kw. Input
2 in. by 12 in.	96 ft. per min.	side and edge	Avg. 38.2 Max. 50.1 Min. 31.9
2 by 4 in.	96 ft. " "	" " "	Avg. 31.4 Max. 35.6 Min. 26.5

For transferring cants from the main rolls past the head saw to the storage platform in front of the gang saw, an overhead crane transfer is provided (shown at top of Fig. 32). The hoisting and propelling motors are series-wound, direct-current machines, and are supplied from a motor-generator set.

REFUSE

The refuse from the various sawmill manufacturing processes consists of dust from the saws, edgings, trimmings, and shavings from the "green" planers. Figs. 33 and 34 show conveyer drives. V-shaped troughs in which chain and block conveyers run, serve to handle the sawdust from the main mill machines, but from the planing machines the shavings must be carried

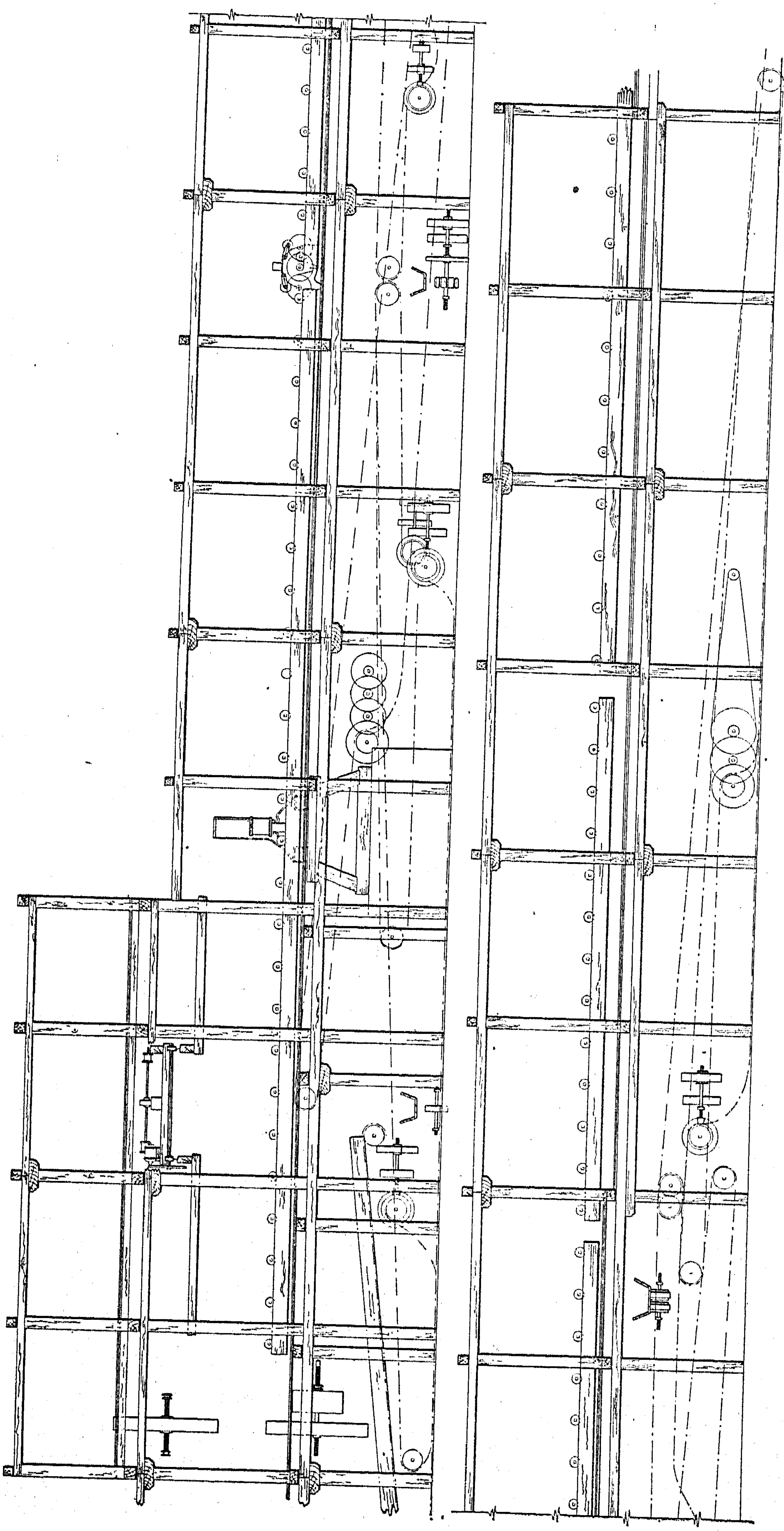
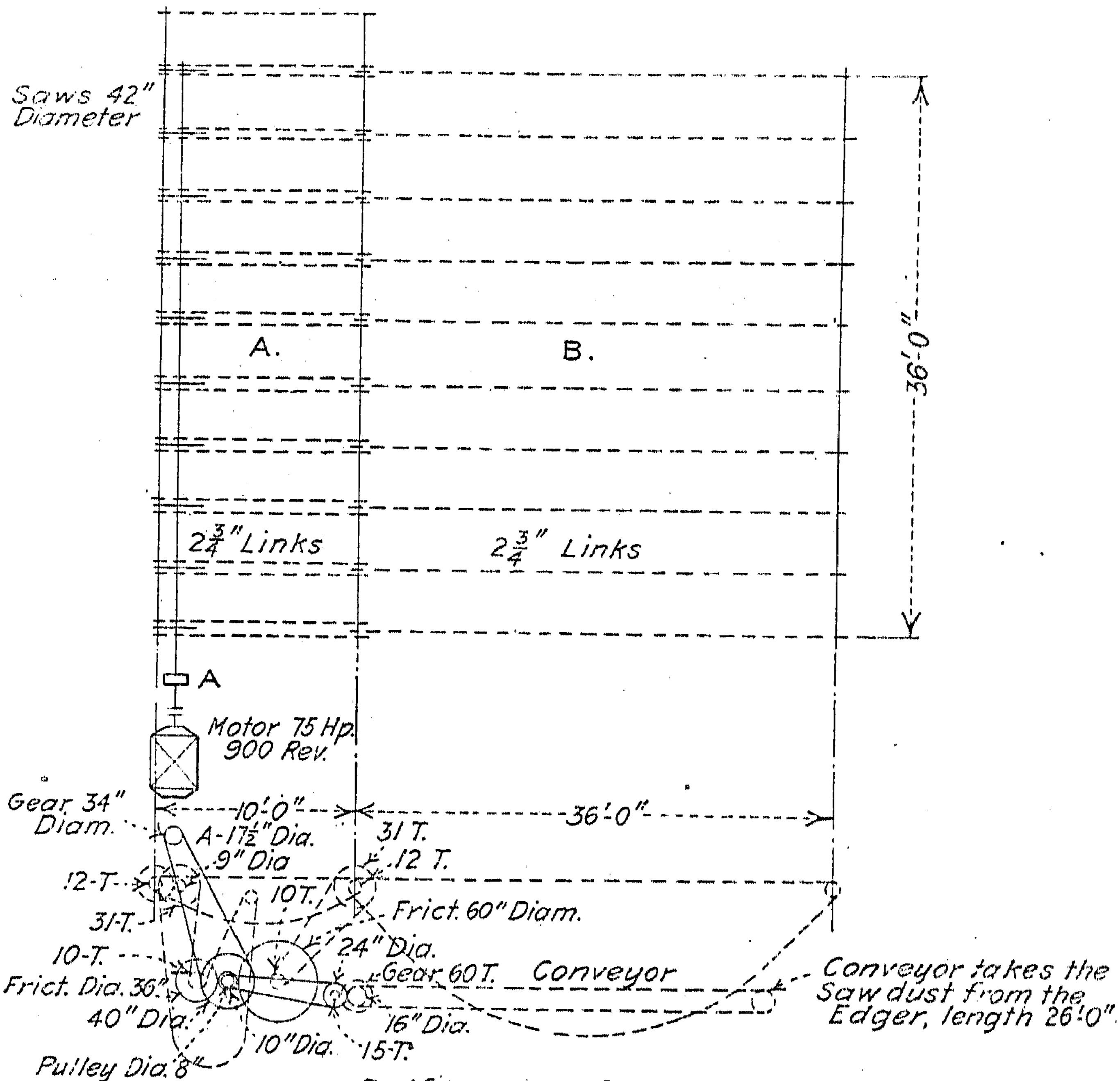


FIG. 32—SIDE ELEVATION OF MILL

away from the knives as fast as possible, so that some pneumatic suction system is necessary.

The edgings are first run through a gang of crosscut saws, a " slasher " with saws spaced 4 ft. (1.22 m.) apart. See Fig. 35. These slabs fall directly into the main mill wood conveyer, which has already received the stub ends from the trimmer which were less than 4 ft. (1.22 m.) long. From this conveyer, Fig. 36, is taken the stock for the lath mill and wood saws. The waste which is suitable for neither of these purposes, continues to the " hog " and the refuse burner, Fig. 37. The " hog " hashes the refuse into small pieces suitable for use under the boilers, after which it is conveyed to the fuel storage bins. These appliances run at constant speed, and have fluctuating demands.



Perif. Velocity of Saws 165 Ft. Sec.
Velocity of Chains Transfer A. 25.7 Ft. Min.
" " " " B. 58.2 " "
" " Conveyor 137.5 Ft. Min.

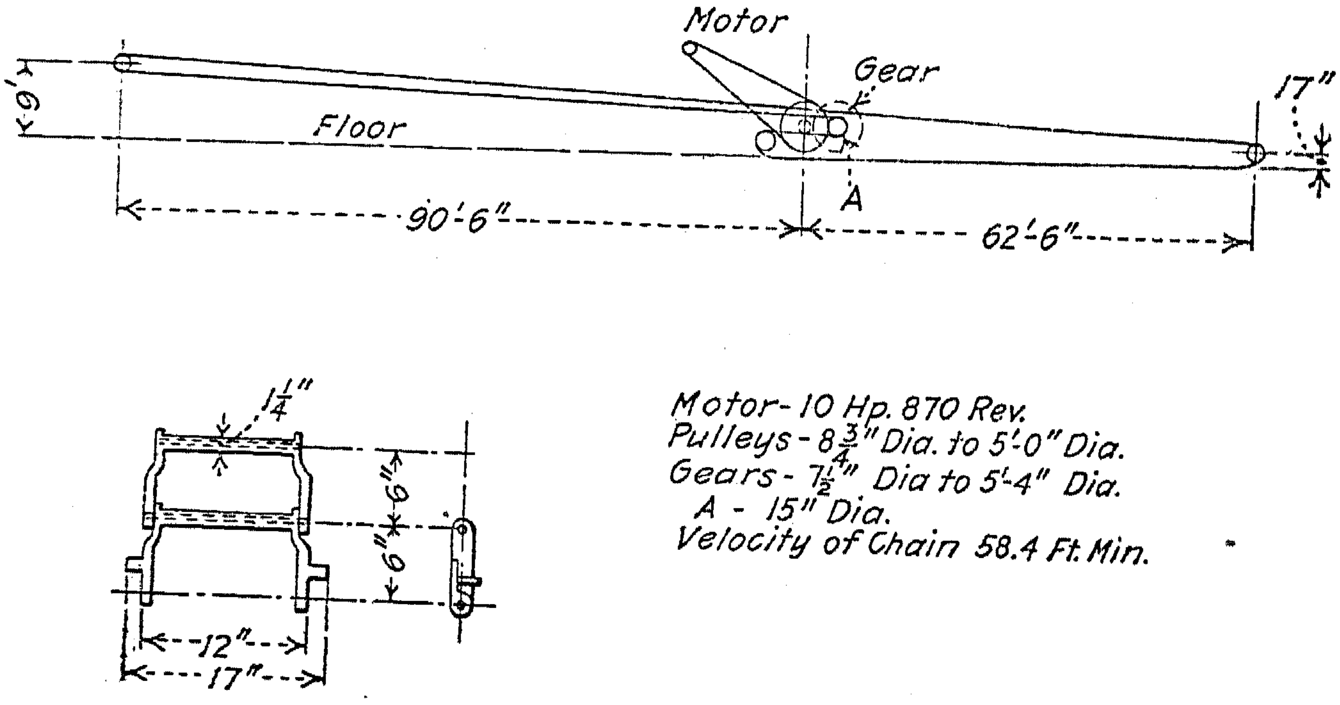
FIG. 35—SLASHER

Dust from the machines is dumped into a main sawdust conveyer, which in turn delivers into the conveyer at the fuel bins. The shavings from the sizers are lifted by suction to a collector and from here blown directly to the fuel bin, Fig. 16.

Piping is usually large, because of the tendency of sawdust, if at all damp, to pack tightly at bends. Low pressures such as can be delivered by centrifugal fans are the rule. The pressure seldom exceeds 5 oz., but the volume is constant and consequently the blowing system is quite extravagant of power. The sawdust and hog fuel from the saw mill, planing mill, etc., if used for generating steam, is more than ample for the total power requirements of the mill. (See table of refuse fuel values at end of paper.)

BURNERS

Fig. 37 shows a typical burner in which the excess refuse and poor quality slabs are disposed of. These refuse consumers are a source of large expense to the mill operators. They must be substantially constructed; at the base, they are lined with fire brick, and sometimes they are water-jacketed to quite a height. The first cost of a burner such as shown in the illustration is approximately $10,000. For a mill with a capacity of 150,000 ft. b. m. per day, the upkeep expense of such a burner would be approximately $1200 for interest and depreciation, and $1000 for maintenance. The life of an average burner is about 10 years.



Motor- 10 Hp. 870 Rev.
Pulleys - $8\frac{3}{4}$" Dia. to 5'-0" Dia.
Gears - $7\frac{1}{2}$" Dia to 5'-4" Dia.
A - 15" Dia.
Velocity of Chain 58.4 Ft. Min.

FIG. 36—REFUSE CONVEYER DRIVE

HANDLING

From the sorting table the lumber is placed in bundles ready for handling. The most efficient method where location permits, appears to be by the well-known overhead monorail (Figs. 38, 39 and 40). The cost of handling by this method averages about $.10 to $.14 per M ft. b. m., which includes all expenses in connection with the system after the bundle is picked up until it is placed in the storage yard or deposited at the dry kiln. This cost covers all charges against the system for labor and operating.

The first cost, installed, of such a system is $4.00 to $5.00 per lineal foot of track, including the hoists, and it provides about 2000 ft. b. m. storage space per foot of track. The monorail is usually operated by direct current power at 250 volts, requiring a motor-generator set or small direct-current steam-operated set. The cost of handling with trucks and horses is approximately 25 cents per M ft. The horses are giving way, however, to storage tractors (Fig. 41), with the result that the above cost is reduced to approximately 10 cents per M ft. for average distances of handling.

For long hauls, storage battery or industrial type trolley locomotives are used. Traveling cranes of the bridge or gantry type are used by some of the larger mills. Fig. 42 shows a representative installation of this character. All of these installations have shown a very satisfactory saving in the expense of handling lumber.

FIG. 40 MONORAIL STRUCTURE DETAIL.

PLANING MILL

As before mentioned, the material for this mill has usually been subjected to a drying process, either natural or artificial. All of the machines are designed for constant-speed drive, the variations in rate of speed being accomplished by changing the sizes of the feed roll driving pulleys. A general planing mill layout is shown in Fig. 43.

Power demands of planing machines have increased somewhat in the last few years, due to the development of fast-feed planers. This increase, however, has not been accompanied by a corres-

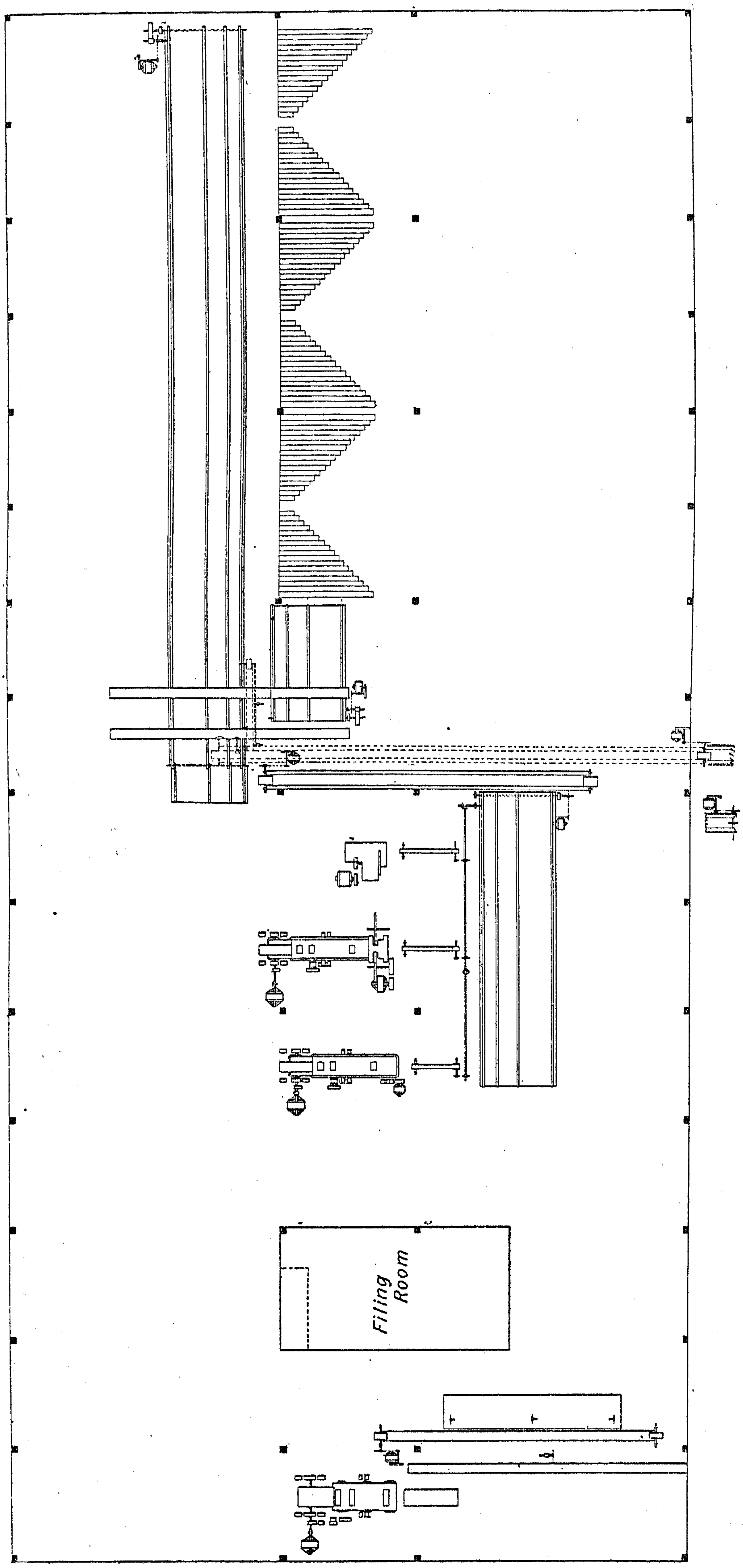


Fig. 43—Planing Mill Layout

ponding increase in motor sizes, as the present tendency is to utilize more fully the rated capacity under usual conditions, operating the motor at overloads when handling the heavier stock. It is universal practise to directly connect constant-speed, squirrel cage motors to the machine driving shaft, using a flexible coupling. Profile attachments are more conveniently operated by an individual motor driving the two profile cutting heads.

The starting duty of planers is rather severe, due to the large masses to be accelerated to high speeds. To this is traceable the common fault of "over-motoring" which was so much in evidence with the older, medium-feed machines. The advent of welded end-ring rotor construction has removed this obstacle.

The running load is fluctuating according to the small irregularities in the dimensions of rough stock. Friction load is approximately 55 to 60 per cent of the working load. The working factor of a planer seldom exceeds 60 per cent of its maximum capacity, since some time is lost in locating rough stock for the operator, and in changing from one size stock to a different size. Standard profile attachments run at constant speed and require 15 h. p. The starting duty is light and the running load fairly steady. Fig. 44 shows the main driving motor and profile attachment motor for a modern fast-feed matcher, and Fig. 45 a 60-h.p. motor driving a timber sizer in a planing mill which is called upon to perform a variety of operations, depending upon stock demands.

COMBINATION MATCHER AND RE-SAW

On orders which will permit one side rough, the re-saw simply splits the stock after it has been properly surfaced. The power requirements of the matcher end do not vary from standard machines. The re-saw (diameter of wheel 54 in. or 1.37 m.—saw blade 7 in. or 18 cm.) requires 35 h. p. to drive it. The motor is mounted on top of the re-saw frame and its weight is supported by a counterweight from a sheave attached to the ceiling. The best method of drive for a re-saw so mounted is by a silent chain. The matcher end requires a 50-h. p. motor. (Fig. 46).

In isolated instances, fast-feed matchers have been fitted with individual motors for driving the various elements of the machine, *i.e.*—one motor driving the feed rolls and one for each cylinder or knife drum, etc. A modern fast-feed planer, size 6 in. by 15 in., feeding 200 to 250 ft. per min., requires motors as follows: top cylinder geared with cloth pinions to a 35-h.p. motor, bottom cylinder to a 20-h. p. motor, side heads to 15-h. p. motors, feed rolls to a 15-h.p. motor.

Such refinements have shown an actual saving in energy over the one-motor method, since all belt friction and slippage is eliminated. The high speeds required for the various parts of the machine, some of which do not fit standard speeds of a 60-cycle motor, made it necessary to resort to gearing with cloth pinions. Very satisfactory results have been obtained.

After being finished, the product from the planers is trimmed to remove defective portions; it is then sorted and bundled. Old practise required a trimmer table with a swing cut-off saw (Fig. 47) for each machine, the output being handled by hand after leaving the machine. Their work is very intermittent and the starting load is light. Squirrel cage, constant speed motors are used, the usual size being three h. p. Tests of a 20-in. saw follow:

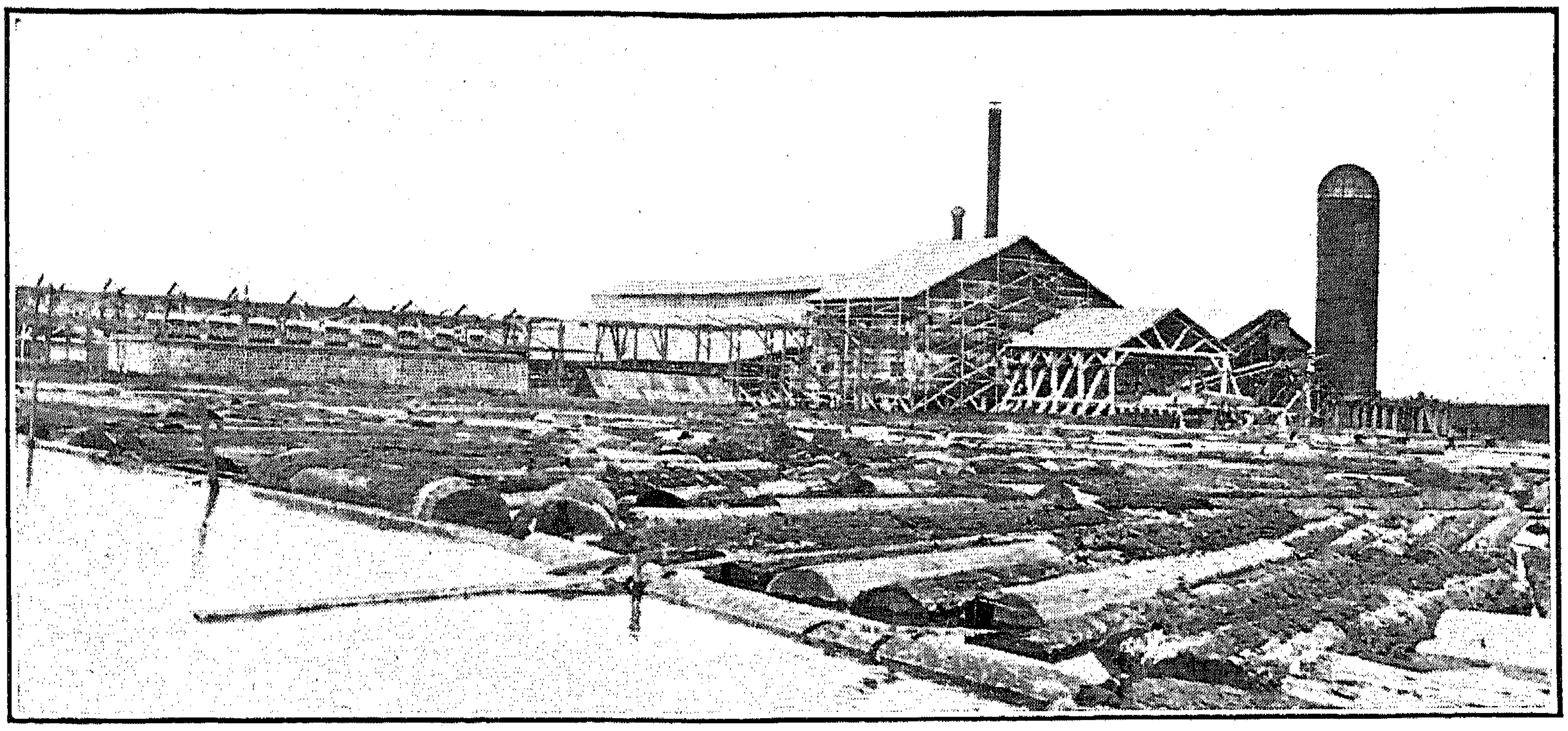
Running light	1.2	kw. input
Cutting one 2 x 4 in.	3.8	" "
" two 2 x 4 "	4.8	" "
" three 2 x 4 "	7	" "
" one 2 x 6 "	5.1	" "
" one 2 x 12 "	6.2	" "
" one 1 x 6 "	2.7	" "
Approx. load factor	30 per cent	
Demand factor	300 per cent.	

The duration of a cut is very short, otherwise the size motor ordinarily employed would have to be materially increased.

The advent of fast-feed planers and matchers necessitates a greater capacity method of handling the output without entailing a too great labor addition. The scheme adopted is to group all planers so that their output falls upon a transfer table. At the end of this table is installed an automatic trimmer similar to but smaller than the saw mill trimmer. In this way one man can trim the entire output. A squirrel cage constant-speed motor furnishes a satisfactory drive, 25 h. p. being the average size motor adopted for this service.

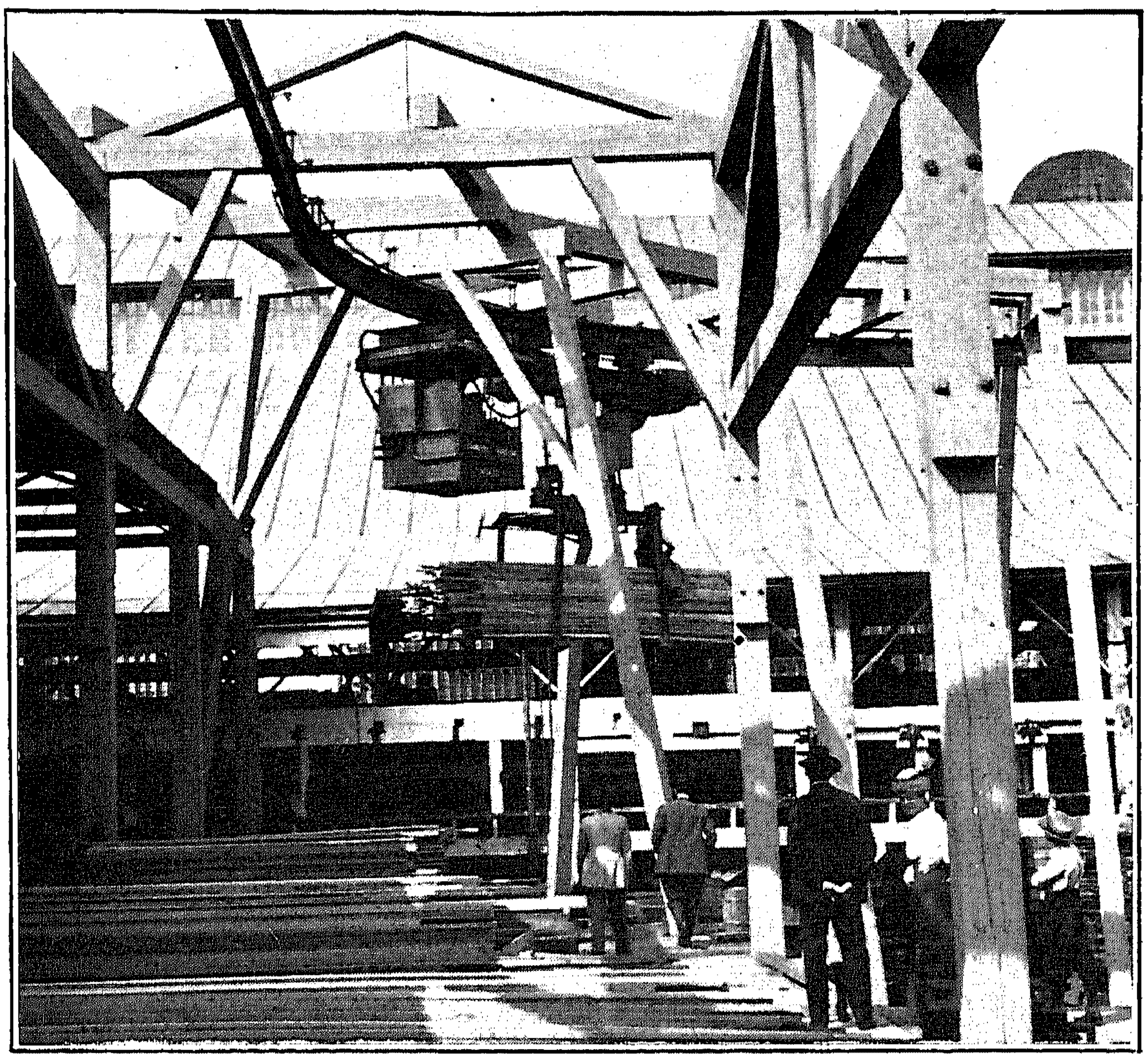
The transfer tables and refuse conveyers in a planing mill are usually operated by back-geared wound-rotor motors with chain drive. The material to be handled is very light, requiring at maximum three- to five-h.p. motors for such service. (Fig. 48).

Besides the trimmings, the other refuse from the planing mill consists of dust from the saws and shavings from the planers. The sawdust and shavings are cared for by air suction and blower systems (see Fig. 16 for typical layout). Usually



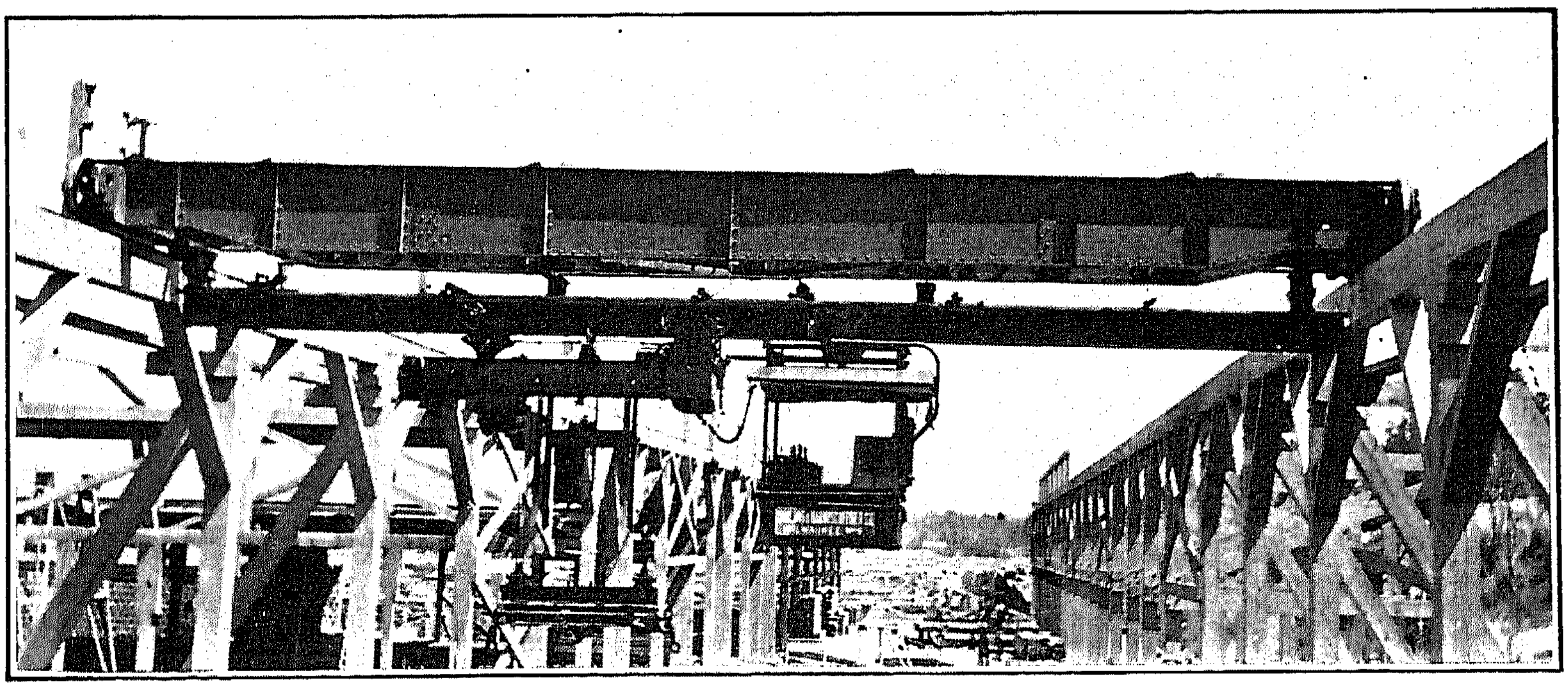
[WHITNEY]

FIG. 37—VIEW ACROSS LOG POND, SHOWING REFUSE BURNER



[WHITNEY]

FIG. 38—MONORAIL CAR WITH LOAD FOR DRY KILN



[WHITNEY]

FIG. 39—MONORAIL CAR AND TRANSFER CRANE FOR SPOTTING CAR AT DIFFERENT SECTIONS OF SORTING TABLE

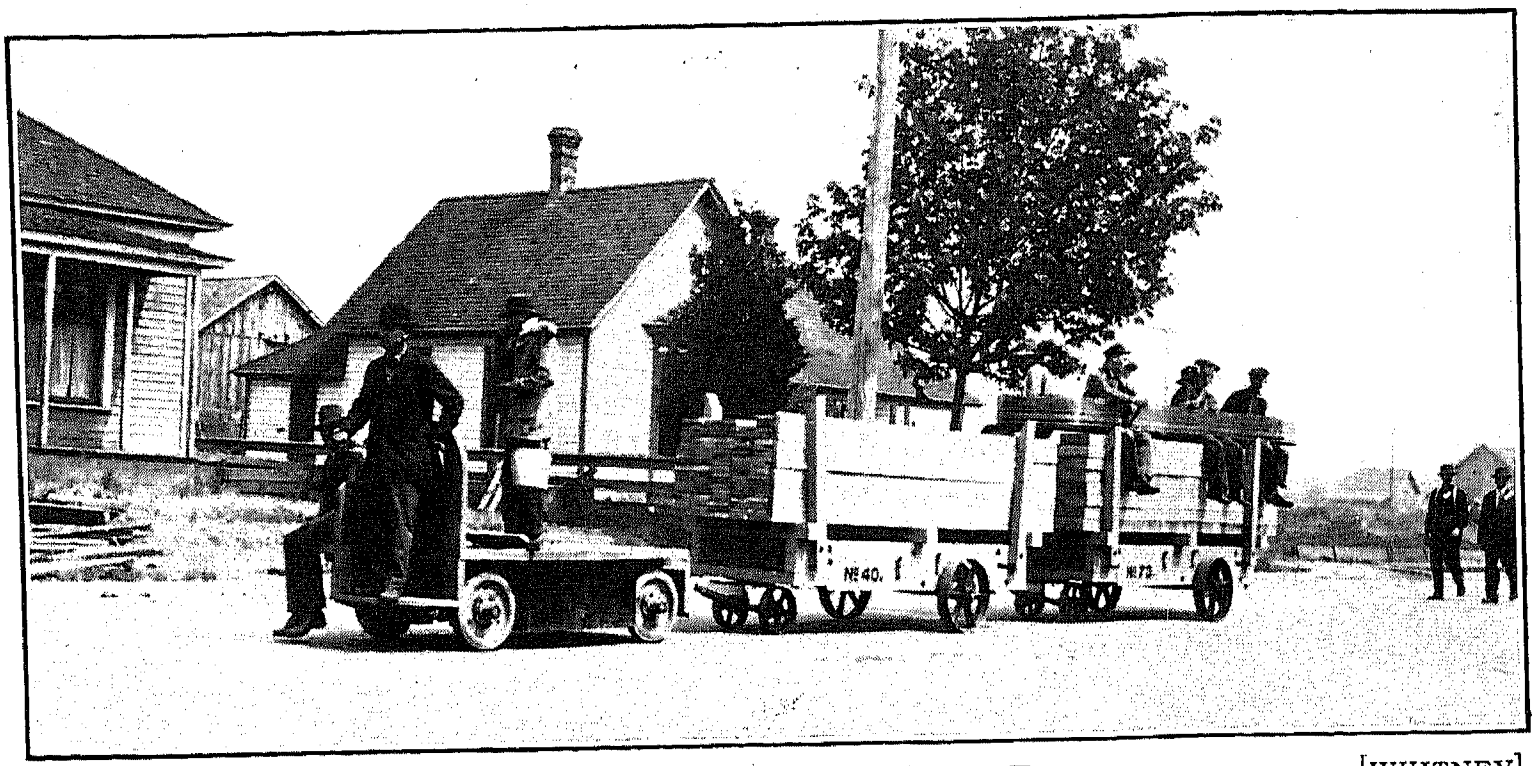
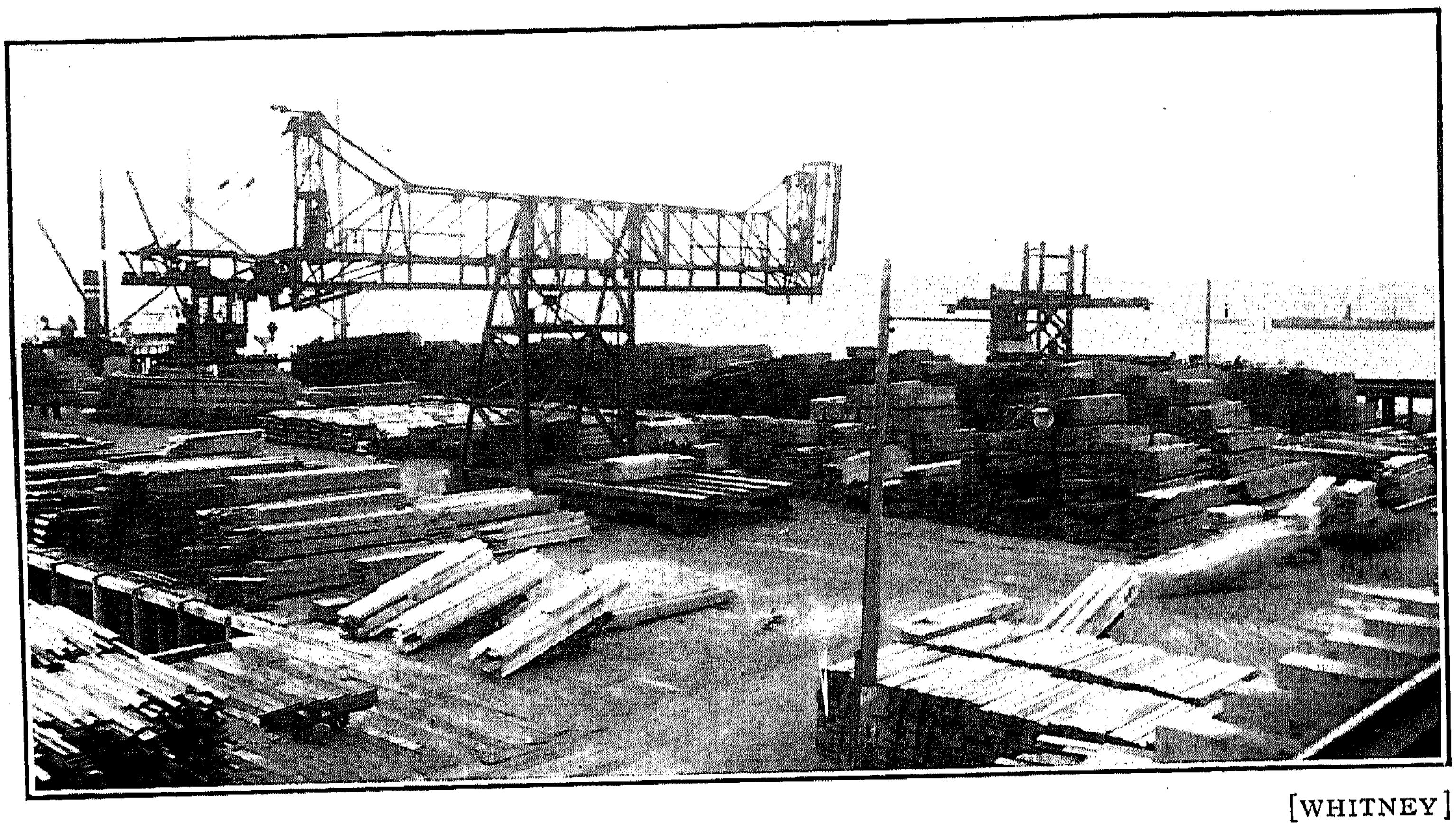
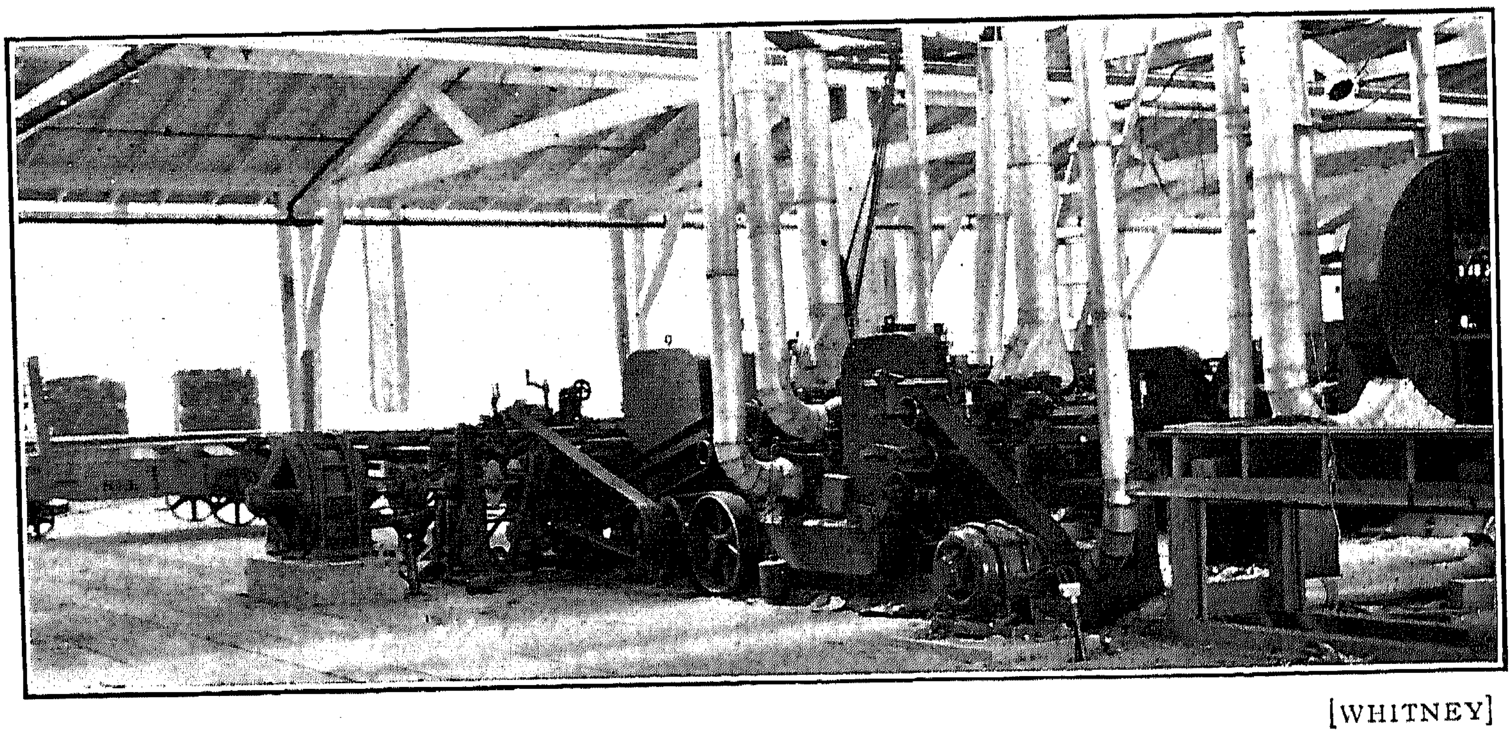


FIG. 41—STORAGE BATTERY TRACTOR [WHITNEY]



[WHITNEY]

FIG. 42—FOUR-TON MONORAIL LUMBER-HANDLING CANTILEVER CRANE, 106 FT. TROLLEY TRAVEL, HAMMOND LUMBER COMPANY, ASTORIA, ORE.



[WHITNEY]

FIG. 44—MATCHER WITH 50-H P. MAIN MOTOR AND 15-H.P. PROFILE ATTACHMENT MOTOR

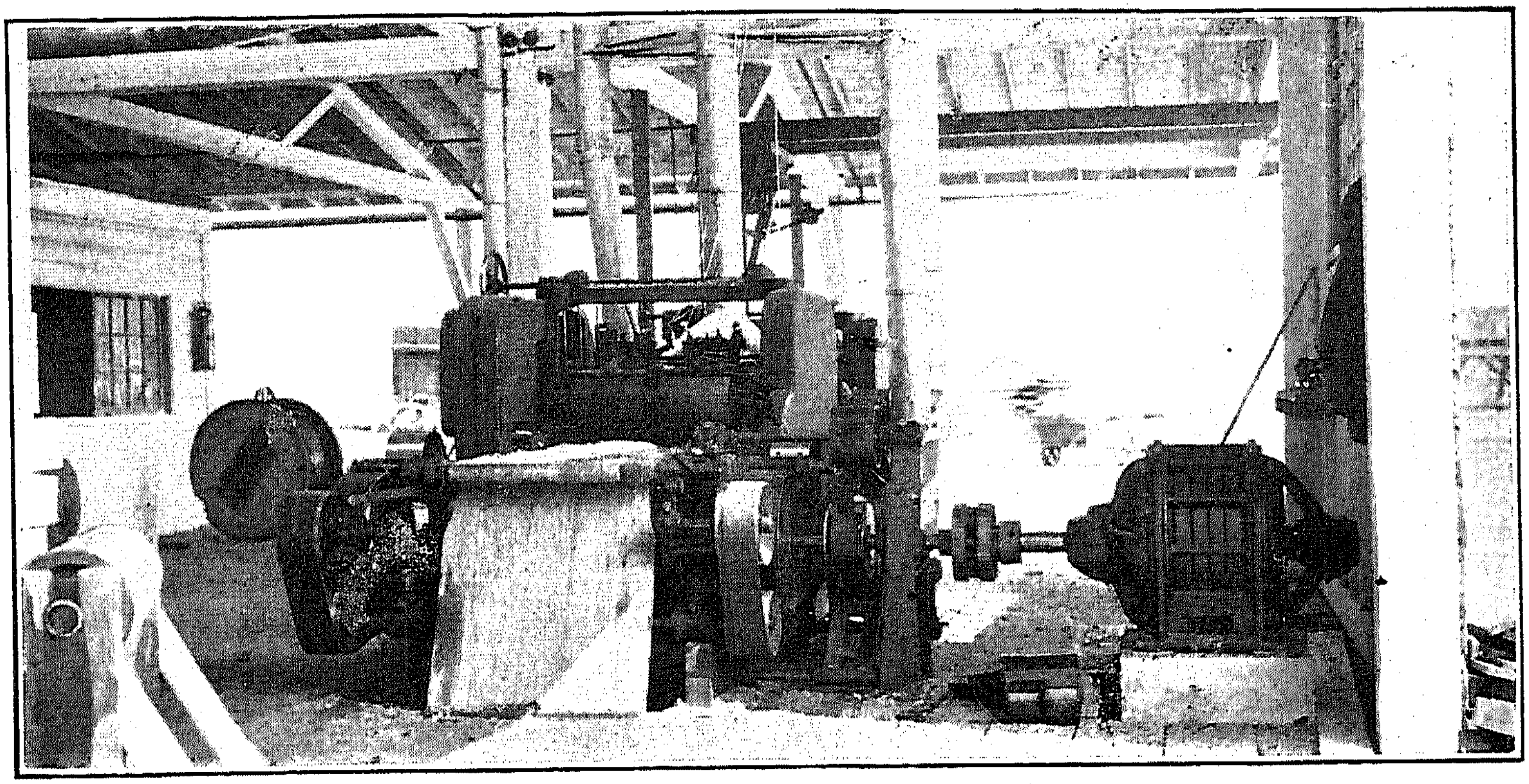
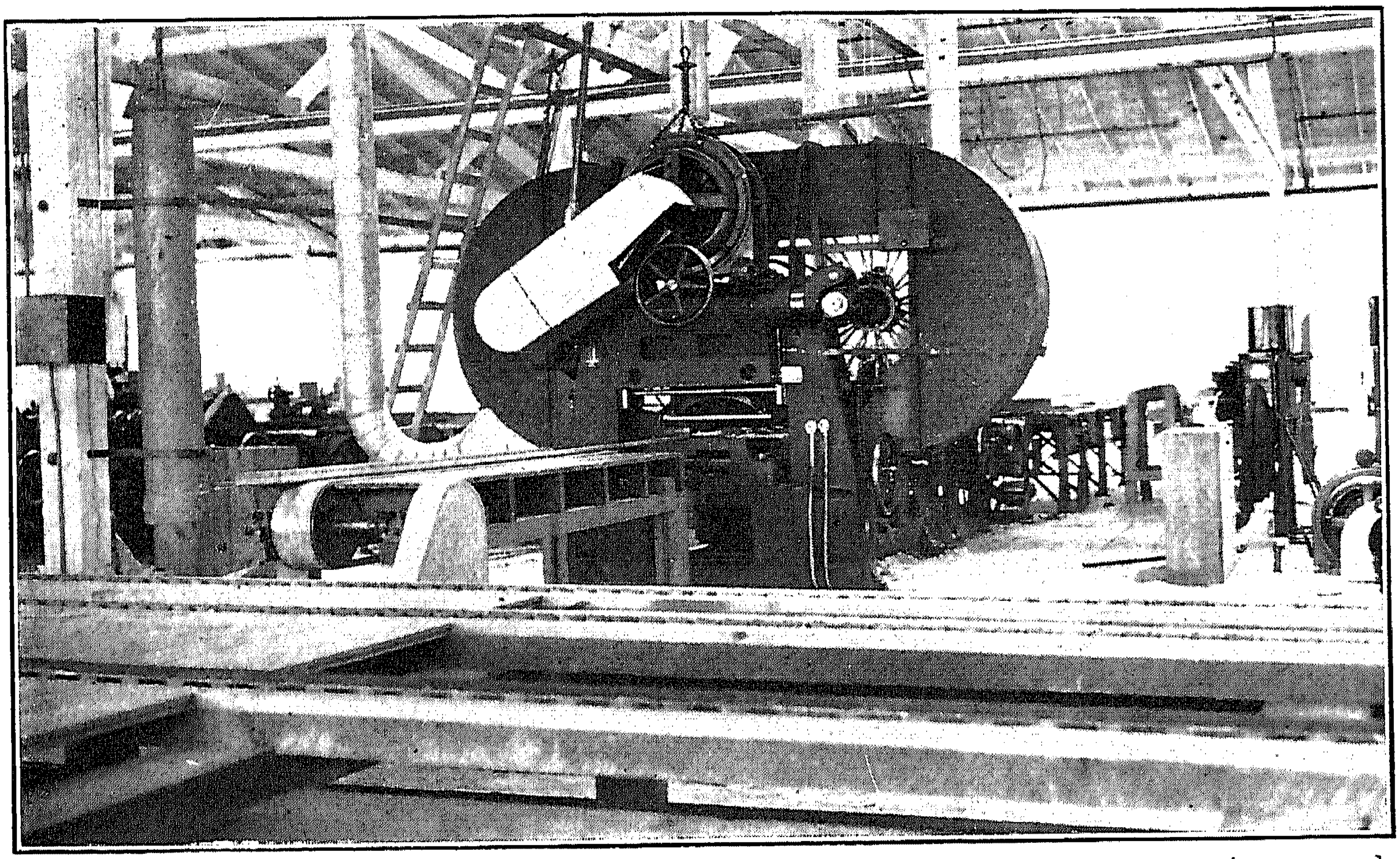
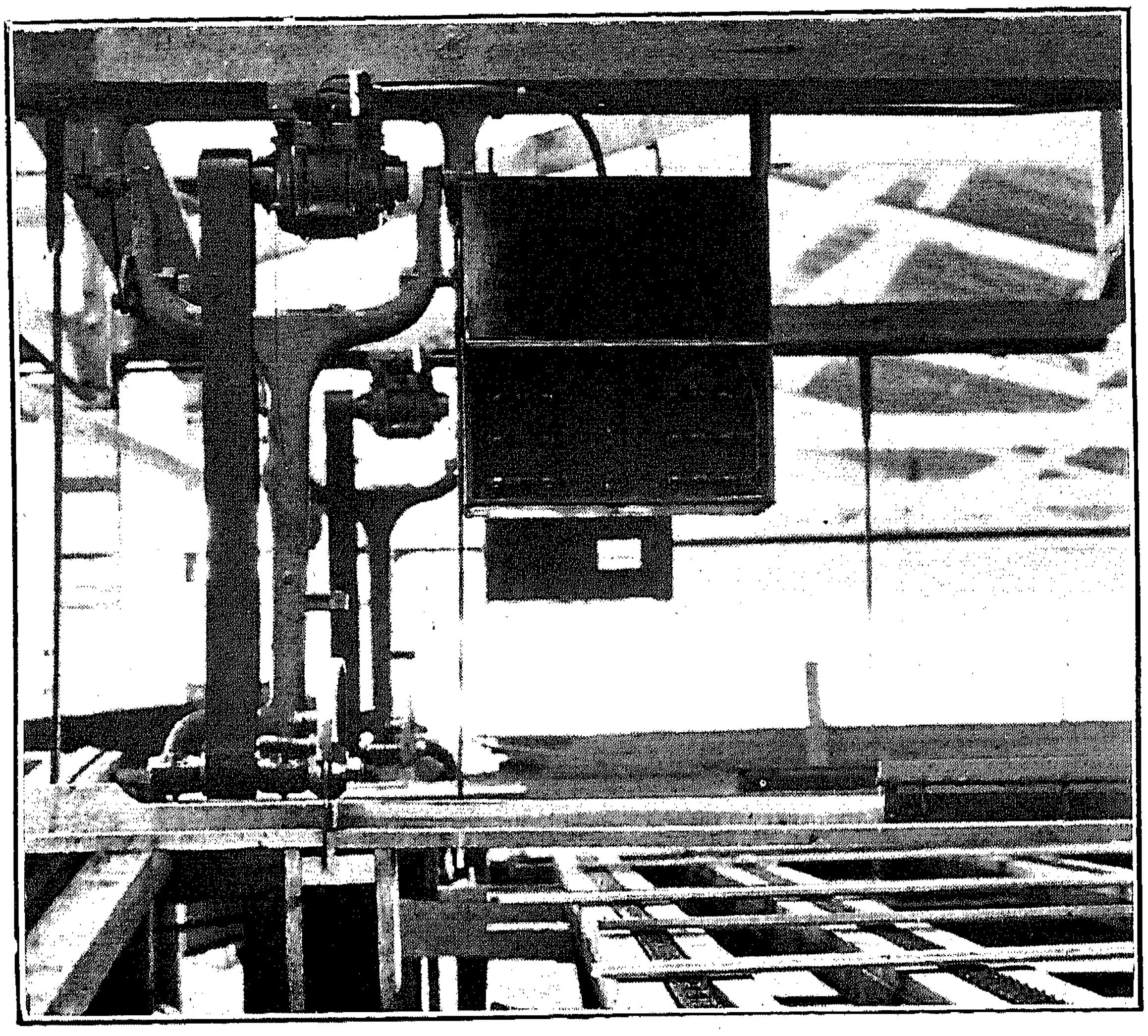


FIG 45—TIMBER SIZER [WHITNEY]



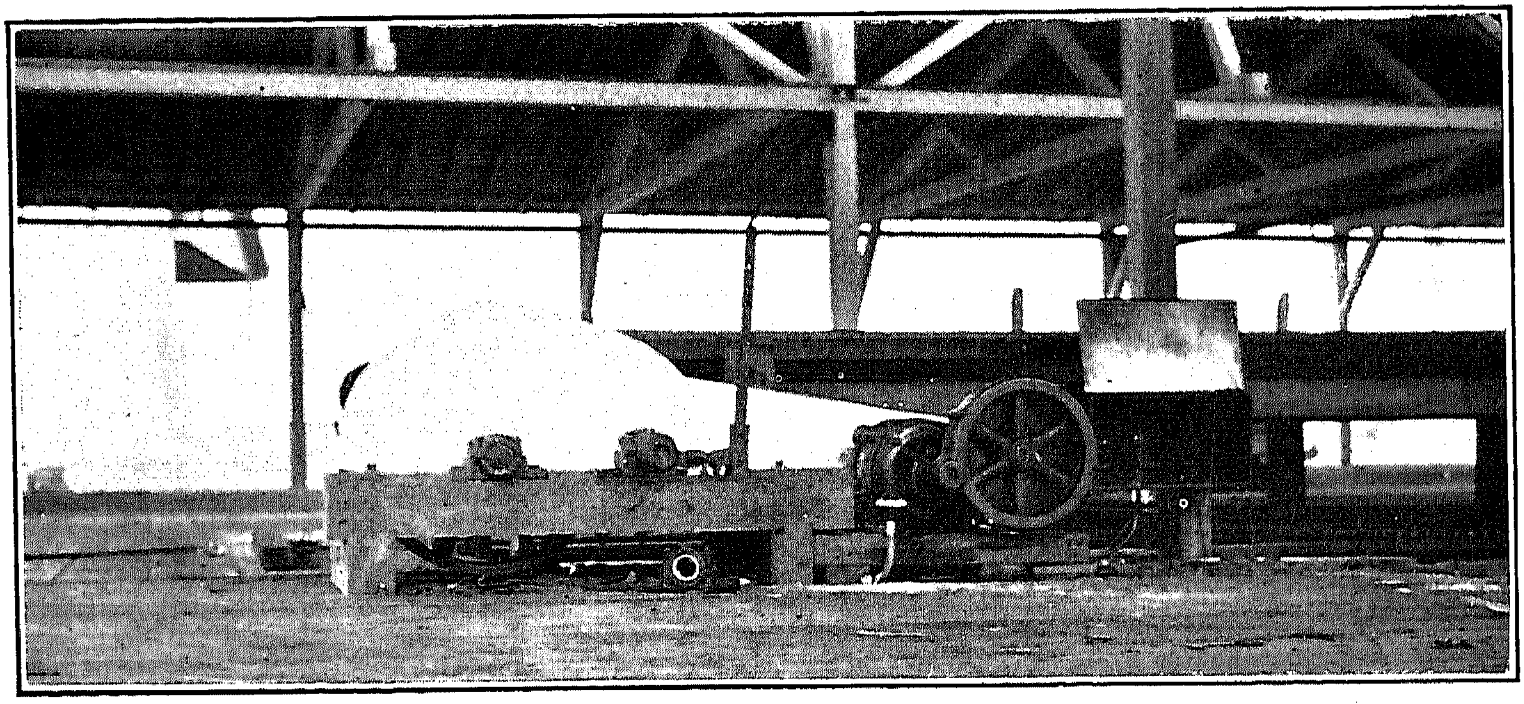
[WHITNEY]

FIG. 46—RE-SAW END OF COMBINATION MATCHER AND RE-SAW, WITH MOTOR MOUNTED ON RE-SAW FRAME AND DRIVING BY SILENT CHAIN



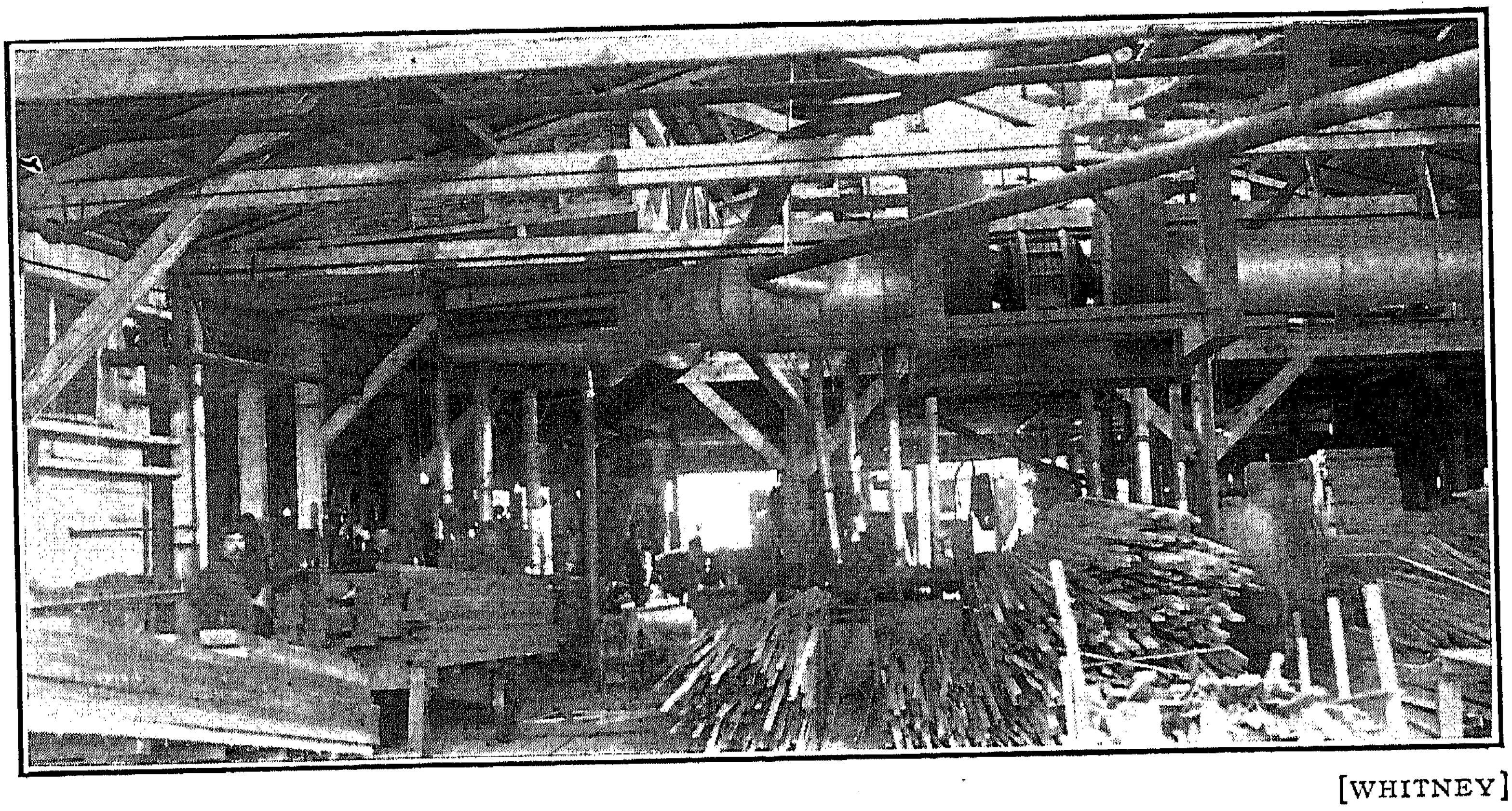
[WHITNEY]

FIG 47—SWING CUT-OFF SAWS FOR TRIMMING PLANING MILL STOCK



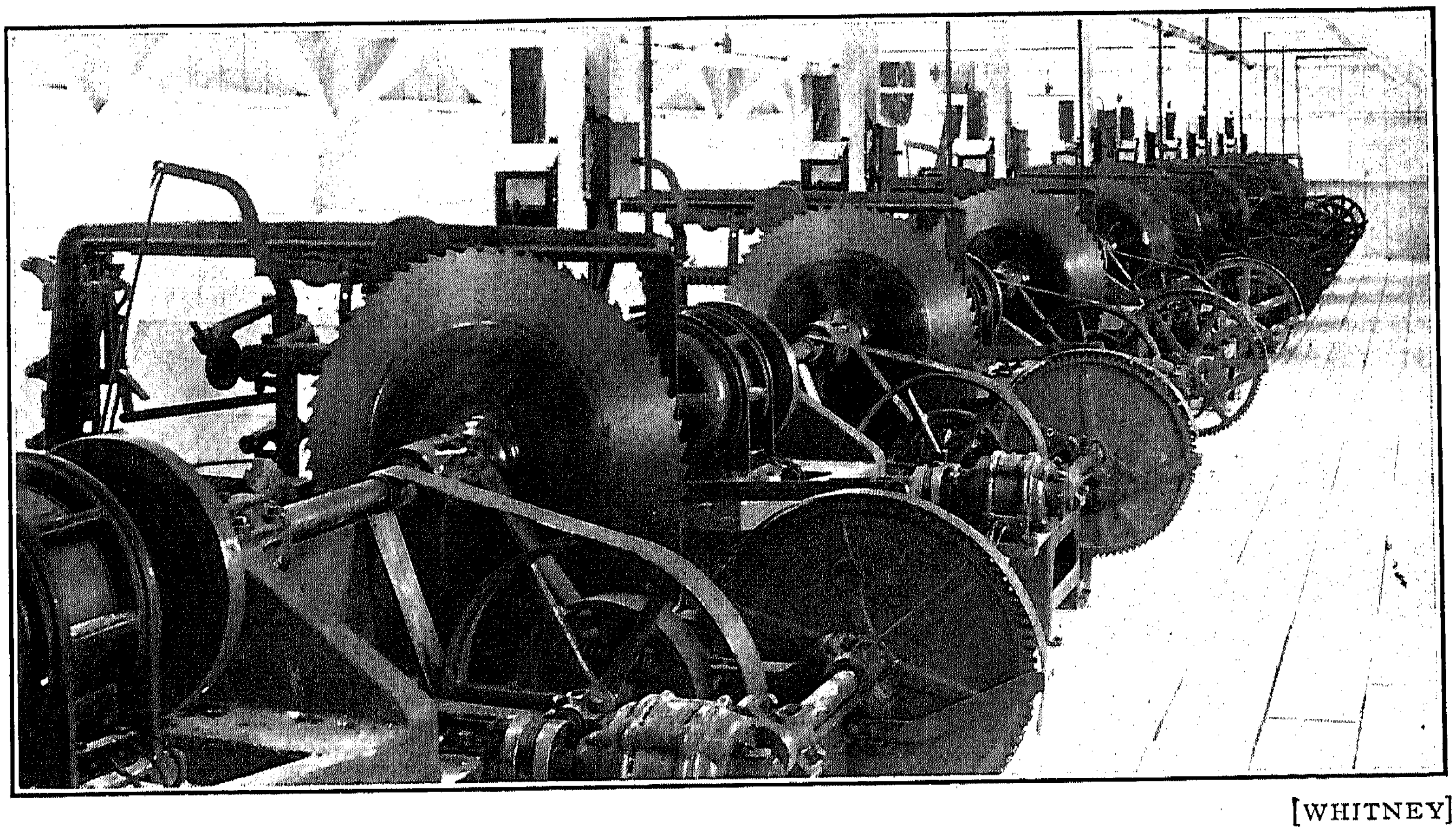
[WHITNEY]

FIG. 48—SORTING TABLE DRIVE IN PLANING MILL, WITH BACK-GEARED MOTOR



[WHITNEY]

FIG. 49—DOUBLE 60-IN. EXHAUST FAN DIRECT-CONNECTED TO MOTOR



[WHITNEY]

FIG. 52—INTERIOR OF SHINGLE MILL USING ELECTRIC DRIVE. THE COMPACT MACHINES AND ABSENCE OF TRANSMISSION BELTING IS IN MARKED CONTRAST TO THE CROWDED APPEARANCE OF BELT-DRIVEN MILLS

the trimmings are put through a small-capacity hog and then handled by the same blower system, or conveyed to a wood bin for the local wood market.

REFUSE EXHAUST SYSTEM

Ordinary centrifugal fans capable of giving 5 oz. pressure are commonly used. Motors are sometimes direct-connected to the fan impellers, but more often belted, since with the latter arrangement the speed of the fan can be changed from time to time to get the correct pressure required in the system. With direct-connected fans, the impellers are ordinarily pressed directly on the motor shaft extensions, the motor bearings caring for the slight additional weight of the fan impeller. Fig. 49 shows such an arrangement. Constant-speed motors are used for this service. The load is practically constant throughout the operation, and is slightly less when the planers are working than when idle, provided of course that the suction intakes are left open at all times. Double fans are ordinarily used, one side lifting the refuse and the other side blowing through the pipe line to the fuel bin.

It is common practise to install a simple low-pressure gate in the suction to each machine, so that that particular intake may be isolated when the machine is shut down, thus reducing the energy required.

The following is indicative of the average power requirements of fans under usual conditions, length of pipe line, intake openings, etc., being assumed normal;

Single	40-in.	fans	20 h.p.
"	50 "	"	25 "
"	60 "	"	35 "
"	70 "	"	50 "
Double	40 "	"	35 "
"	50 "	"	50 "
"	60 "	"	75 "
"	70 "	"	100 "

Another system which has proved economical in energy consumption makes use of a low-pressure centrifugal fan for suction only, and uses high pressure for blowing the dust through the pipe line to the fuel bin. With centrifugal fans used for both suction and blowing, all of the material handled is passed through the impeller itself, necessitating large clearances and a consequent loss in efficiency. With the high-pressure system, none of the dust or chips passes through the fan itself, but the discharge from the collector empties into a revolving drum with vertical cylindrical compartments. The cylindrical cartridges thus formed are forced through the pipe line as each compartment revolves under the compressor discharge. Centrifugal compressors and positive pressure blowers find a wide field in the high-pressure system.

SHINGLE MILLS

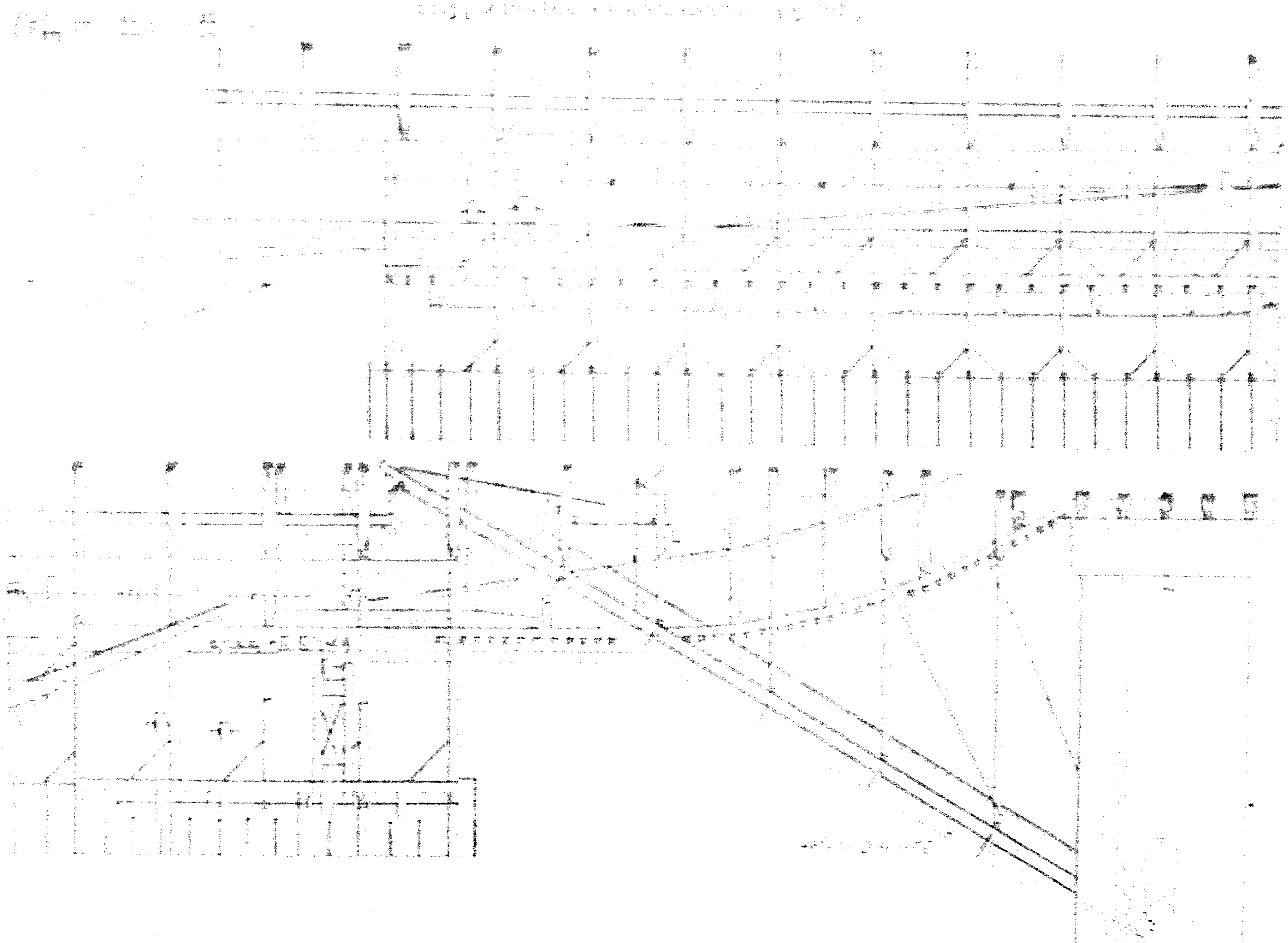
Figs. 50 and 51 show the latest tendency in the layout of shingle mills. The logs are handled in the same way as in a saw mill, after which they are cut into bolts, which go to the shingle machines and are finally trimmed, sorted, bundled and dried. Fig. 51 gives the main floor plan of an electrically driven mill, while Fig. 50 shows the elevation of a later mill. The latter was originally planned for steam drive, but later changed to electric, so that the elevation shows a line shaft in error. In the final plans, this was eliminated and the driving motors connected to the shingle machines, as in Fig. 51. Fig. 52 shows the shingle machine floor of this mill, which is the first, of which we have record, using individual motor drive throughout. Its operation has been very satisfactory. Of all the machines used in these operations, only the shingle machines, shown in Fig. 52, differ from those already described for other operations.

The standard upright shingle machine requires two motors for its best operation—a 20-h.p. motor driving the main saw and mechanism and a 3-h.p. motor driving the trimmer saw—both constant-speed, squirrel cage motors direct-connected to the driving shafts. The power requirements of the complete machine—both the shingle saw and the trim saw—are about 18 kw. input, no-load, and 20 to 21 kw. input when cutting.

GENERAL

In general it is estimated, in a mill using steam engines with line shaft drive, that 8 to 10 h.p. per M feet b.m. capacity per 10-hour day, is required for the sawmill machinery only. This old rule-of-thumb method was close enough for practical purposes, since with maintained steam pressure the engines had large overload capacities, but with very poor speed regulation. This poor speed regulation is noticeable in almost all steam-driven mills. The friction load is enormous, requiring often 40 per cent of the rated engine power when running the mill idle.

With the advent of electric drive, the motor horse power installed will approximate 11 to 13 h.p. per M feet b.m. capacity per day, for both sawmill and planing mill.



The energy required for manufacturing 1000 ft. b. m., including planing mill operation, has been found to vary from about 29 kw-hr. in the white pine district to 46 kw-hr. in the fir district of the Pacific Coast, which would indicate an actual electrical horse power of from 3.8 to approximately 6 h.p. per M feet daily capacity of an electrically operated mill.

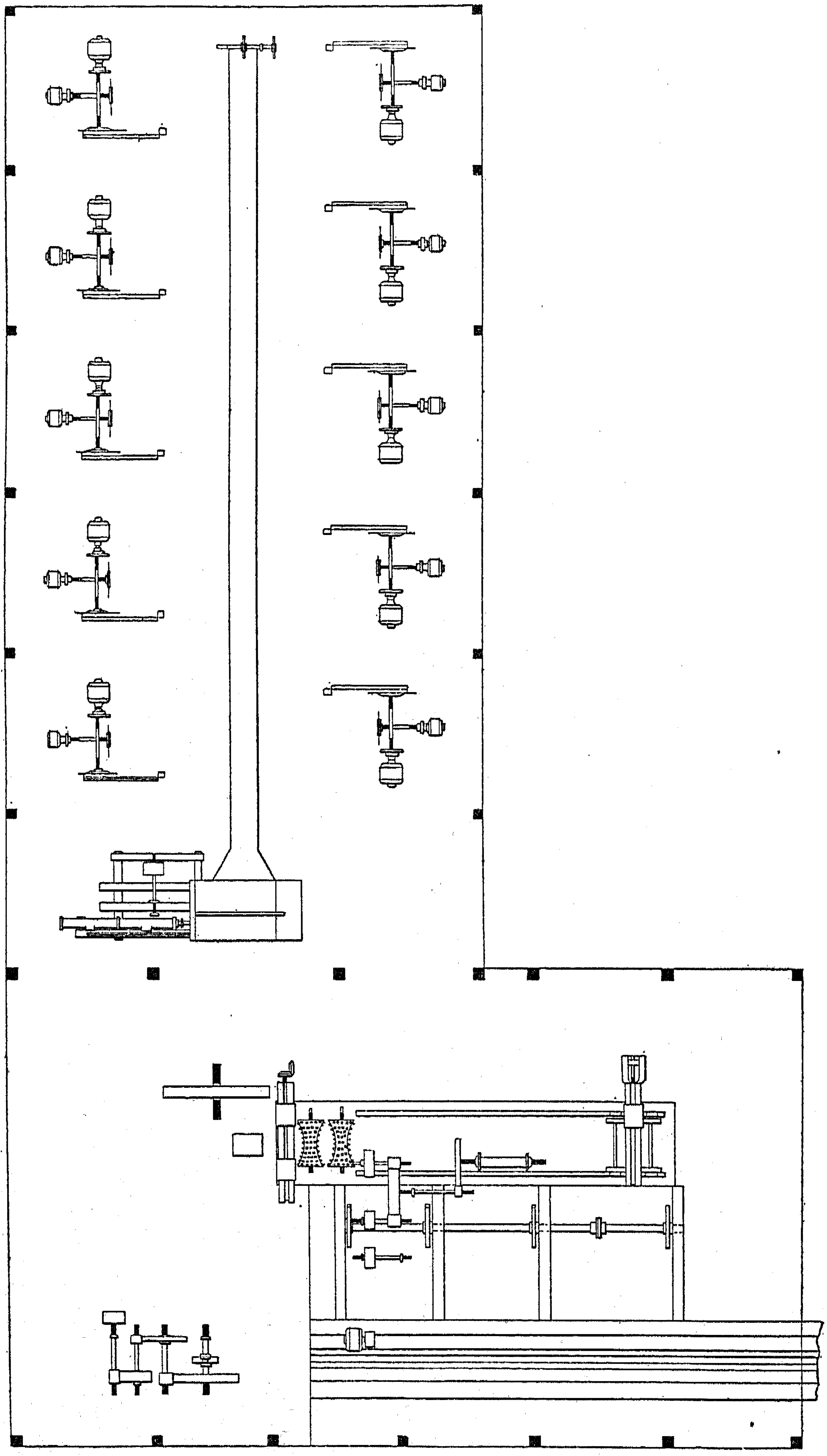


FIG. 51—SHINGLE MILL PLAN

The cost of power to the average saw mill operator means very little, due to the large wastes which they must experience in their manufacturing operations. Those mills located remote from any available market, must dispose of this waste either by generating power for their own use or consuming it in refuse burners.

REFUSE—USES AND FUEL VALUE

The question of refuse disposition is one of the large items of expense in connection with the average mill. A solid log scaling 1000 ft. b.m. will, when cut, give about 1150 ft. b.m. of lumber, and the refuse in the form of sawdust, trimmings and edgings will amount to a little more than a half cord, or the equivalent of 115 cu. ft. of cut fuel. Adding the refuse from the planing mill and other manufacturing departments, the total loss may easily reach 40 per cent of the original scale of the log. Of course the greater refinements in using the by-product will reduce the proportionate amount of refuse.

Except for fuel, the uses for this have been very narrow. Attempts have been made to use sawdust from Pacific Coast mills, which cut mostly fir, spruce and hemlock, for manufacturing wood alcohol and ethyl alcohol. In practise, however, the manufacturing costs run so high that it has proved unprofitable. The latest projected use is in making sawdust briquets to be used for paving purposes, and also for use as fuel. Such a plant has been completed, although its operations have not extended over a sufficient period to determine the ultimate success.

As fuel, the refuse values, wherever there is an available market, are shown by the following data:

Wt. one cu. ft. wet sawdust.....................	21 lb.
Per cent moisture...............................	48 to 52 per cent.
Heat value per lb. wet sawdust..................	3500 B. t. u.

Wet sawdust means that in its natural state coming directly from the mill operations, and includes cut fuel from the hog. The dust from planing mill operation is relatively dry, and as fuel, has a value per pound of 8500 B.t.u. These values are averages of a number of analyses and apply to sawdust from mills cutting mostly fir and spruce. As ordinarily found in the fuel bin, the mixture has some intermediate heating value. Sawdust is usually sold in units of 200 cu. ft., the equivalent of about 0.88 cord of slabwood

Slabwood is cut to 4-ft. lengths and sold by the cord. It also has a wide use as fuel, though as such it is more expensive than sawdust.

The following table gives the average values of wood fuel as compared with oil and coal, the costs of the various fuels per unit being assumed as in column five. Column two gives evaporation values taken from tests at the same plants, using the fuels named.

	B. t. u. per lb. dry fuel	Lb. water evaporated from and at 212 deg. per unit.		Cost per 1000 lb. water from and at 212 deg,	Cost per unit of fuel
Sawdust.........	8,500	(200 cu. ft.)	10,500	9.5 cents	$1.00, 200 cu. ft.
Slabwood........		(1 cord)	12,500	24 cents	3.00, 1 cord
Split cord wood...		(1 cord)	13,500	37 cents	5.00, 1 cord
Oil.............	18,500	(1 lb.)	15	21.9 cents	1.10 per bbl.
Coal...........	11,000	(1 lb.)	7.2	41.6 cents	6.00 per ton

DISCUSSION ON "ELECTRICITY IN THE LUMBER INDUSTRY" (WHITNEY), SPOKANE, WASH., SEPTEMBER 10, 1914.

Mr. Scott: Mr. Whitney's paper is of particular importance to central station men because it shows that there is a field for prospective business open that is usually placed in the same class with steam laundries, that is to say, absolutely unapproachable. I have never dealt directly with any logging men, but have had occasion to attempt to sell power to a few sawmill men, particularly for small plants, none of very large capacity, and their main objection to motor drive is, first, they claim the first cost of the motor installation is excessive as compared with a steam engine; and, second, they say that the motors will not stand up to the work. Now, never having actually seen a drive of that kind I was not in a particularly advantageous position to refute their statements. Third, they say they must have steam anyway for their dry kilns and for their log-carriers, and therefore there is no particular advantage in putting in electric drive. And lastly, they say that they are forced by law to get rid of their waste; in most instances they are too far removed from a point where the waste can be sold as fuel, so they have to install a burner especially to get rid of it, if electric drive is used.

Now, I would like, if possible, to hear some arguments that could be put forth to refute those points of view. So far as central station service is concerned, compared with isolated plant service in sawmills, I should unhesitatingly say that, for an installation having over, say, 1000 e.h.p., central station service could complete with an isolated plant very favorably, provided the sawmill was within a reasonable distance of a transmission line. For mills smaller than that I have not seen enough data to be able to tell.

On page 1323, where a comparison is made between operation of logging railways by electricity and by steam, a saving of about $20,000 a year in favor of electricity is shown. I should think that any logging man, no matter how skeptical, would " sit up and take notice," and at least inquire how that could be done.

There is another question in regard to a sawmill: whether steam operation is less efficient from a time standpoint than a motor drive; in other words, whether more time is saved by motor drive than by steam. When a man drives a headsaw with a steam engine and runs into a stiff cut, the steam engine begins to show signs of distress and slows down, and he eases up on his speed; but with a motor the log goes right straight through. I have had that point put up to me two or three times by sawmill men and they claim it is a fact that there is only one thing for the motor to do under such conditions, and that is to blow the fuses. If I understand Mr. Whitney's paper correctly, the development of the electric motor in the last few years has reached such a point that these difficulties are overcome.

A. A. Miller: Last year at the Vancouver convention Mr. E. J. Barry presented a paper on *Logging by Electricity*, and Mr. Whitney contributed very largely to the discussion. It is apparent that Mr. Whitney has been busy during the past year in collecting further data, which have been very systematically assembled in this paper.

I can remember distinctly that only a few years ago loggers and lumbermen in general would not pay any attention to the proposal to use electricity in their operations. The progress made has been very marked, and no up-to-date designer of sawmills would now entirely pass up consideration of electric drive, but would give it very thorough consideration, and in a fair percentage of cases would determine upon electric drive in preference to the old type.

With respect to the question which Mr. Scott asked as to the difficulty encountered in steam drive where the speed of the carriage is diminished in order to allow the saw to speed up again, and where in case of electric drive it is not so regulated but is allowed to go forward at practically constant speed regardless of the load on the motor—this is due to the inherent ability of the motor to carry, temporarily, heavy overloads, and to give such power as is required to take care of the load that may be imposed upon it. That is somewhat allied to the advantage of electric locomotives, in heavy freight work, over steam locomotives, in that for short intervals the capacity of the electric machine is only limited by the amount of power which you can deliver to it. Induction motors, both of the squirrel cage and wound secondary type, for a number of years past have been designed on sufficiently liberal margin to stand tremendous overloads for a period of a minute or so.

F. D. Weber: About seven or eight years ago, I think, the first electrically driven sawmill in Oregon was installed at Dee. Prior to that time there were absolutely no data on this subject. The mill was fitted with all standard squirrel cage motors, with a 150-h. p. squirrel cage motor placed on a double-cut 8-ft. band mill, and after it was installed it was impossible to start the band mill. The only way which they had to start it, and this method was used for years, was by putting a 4 by 4-in. timber in the upper flywheel and having six or eight men throw their weight on it.

A little river runs within about a thousand feet of this mill, and upon this was installed a hydroelectric generating plant to furnish power for the mill.

When this mill was installed they had no consideration at all for sizes of copper, the mill men installing all the wiring. The writer ran tests under operating conditions and found that the copper was about one-half the proper size for satisfactory operation. There was also trouble with the motor connected to the trimmer. This motor was not of sufficient size and necessitated the shutting down of the trimmer occasionally to allow the motor to cool off.

This lumber mill is owned by the Eccles interests, and they were so impressed with the operation of the first mill that when it burned down about two years ago, they replaced it with another electrically operated mill, although it was impossible with their first equipment to operate the band mill double-cut, because when thus operated the motor was unable to carry the load.

There are some questions which I would like to ask Mr. Whitney:

First, have manufacturing companies ever considered furnishing an enclosed type of motor in certain locations in sawmills? After a sawmill has been operated electrically, this blower system that Mr. Whitney spoke about generally fails to keep the mill clean and a great deal of refuse collects, such as sawdust and chips, to which the motors are exposed, consequently a question of fire hazard arises. I have seen motors completely covered with chips and sawdust.

Second, in regard to the motor of the main carriage, I would like to know whether they have had any trouble keeping oil in the bearings of this motor. I should imagine that it would splash out.

Third, I desire to know whether there have ever been any tests made on the load factor of this mill or any other mill.

Fourth, have there been any figures presented concerning the relative cost of installation of electrically driven mills as compared with the first cost of motors? I have heard the argument advanced that the cost of wiring a modern mill is excessive.

Fifth, are there any data concerning the life hazard in logging woods in connection with electrically operated logging engines? It has been said that this hazard was considerable in dense timber where cutting was taking place continually, which might interfere with the transmission lines. Also, the connection between the portable transformer stations and the logging engines, being subjected to the various accidents of the logging woods, might expose the men to live circuits, and produce a serious life hazard.

J. B. Fisken: I want first of all to note that, if I mistake not, the first article in any of the Institute PROCEEDINGS on the subject of the application of electricity to the lumbering industry was a paper by Mr. E. J. Barry, *Electricity in the Lumber Industry*, presented at Los Angeles in April, 1911. Three years later we get a paper from Mr. Whitney, which seems to me as if it might almost be the last; there may be some small improvements, but from what Mr. Whitney tells us the subject has been pretty nearly covered.

There still remain a few things to be done. The question of drying the lumber will involve the generation of steam unless there is a hydraulic plant available; if there is, the drying of the lumber might be done by electricity. The log carriage is not electrically driven in the case we are considering; the operating man might have difficulty in taking care of that. I think it is a question for the manufacturers to solve. The problem of disposition of refuse is a hard one, but in these days of conservation it would seem that some means might be found to take care of this refuse; it must have some commercial value, and unless the cost of saving it is more than the market value, it should be taken care of.

From the standpoint of the operating man, I think the load would be an objectionable one for the reason that it would be very intermittent and severe. Mr. Weber has asked a question regarding the load factor. In the item of costs on page 1320 Mr. Whitney puts in coal at $4.25 a ton. From conditions as I know them I doubt very much if coal could be laid down at the donkey engine for anything like $4.25 a ton. It costs us more than that to lay it down here in Spokane, and to haul it up to any of the logging plants must add very materially to the cost.

Mr. Whitney discusses methods of handling and conserving the refuse. That is a matter, of course, more for the commercial man than for the engineer; at the same time the engineer should work with those who can settle it, and I hope before long to see the sawmills and wood-working factories entirely operated by electricity. I think it is almost invariably the custom now in putting in a large mill to put in electric drive. We have service in this neighborhood that is typical, and from what I have been able to learn the owners would never think of changing back to steam drive.

L. T. Merwin: There is no question in my mind but that the difficulties due to peak loads in sawmill operation can be successfully worked out. Following actual experience of a number of years in electric hoisting under rather severe conditions, I do not think that the question of extreme momentary demand will remain a serious one, even though at the present time it may seem so.

I want to ask a question of Mr. Whitney bearing on the point that Mr. Weber and Mr. Fisken have already brought out, the poor load factor, the highly fluctuating load and the extreme peaks. Has any consideration been given to the handling of these extreme peaks in a manner similar to that in which extreme peaks of mining loads are handled, as, for instance, by some sort of modification of the Illgner system or by a heavy flywheel set operated by an induction motor? Mr. Whitney mentioned in his paper that of necessity the old manner of running steam-driven mills was from one central drive; I gather that from that they went to the other extreme when first installing electrical drive, and finally have come back to a compromise, with partly group drive. If the flywheel system as applied now to extreme peaks of mining loads can be applied to the sawmill, would that not break down the objections of the central station operating engineer?

Mr. Cheek: As the variable loads that necessarily come upon a motor, it seems to me, would make its protection a very difficult matter, I ask Mr. Whitney what he recommends for the protection of such a motor, whether fuses or other automatic devices. I also ask how the size of the copper is calculated, and whether he has any further information with regard to tests.

I was up in Victoria not long ago and there is a new plant up there that had recently been equipped for making briquets, and they used the refuse, they used the sawdust and also the slabs after going through the hopper; and they claimed that these briquets burn slowly and with much the same characteristics as coal and compared quite favorably with coal.

The matter of the decrease of the fire hazard in logging is a point which I think will act very much in favor of electrical donkeys. This last season was a very dry one and some companies suspended operations during the dry season because of the severe fire hazard of the steam donkey.

A. Norman: The company with which I am connected recently began to supply power to a large sawmill. This mill started in actual operation about three weeks ago, and the mill being entirely new and all of the machinery new, they have not as yet had a full day's operation, and I would not attempt to say just what the load factor will finally be when the mill is in constant operation. However, I could say in a general way that we believe it is going to be about 50 per cent. We feel very much encouraged as to this particular installation, the mill people feel very much encouraged, and I think it offers a fertile field for cooperation between the milling industry and the central station.

In our case, we were so situated that we could furnish this mill not only current for the operation of its motors, but also the steam needed for the dry kiln and for such other purposes as they found it advisable to use steam for. In an installation of some 2100 h. p. in motors I believe we are furnishing them some 225 h.p. for their steam needs. As I say, this installation is so new that we cannot give very full information, but we would be glad to have anyone who is interested in this subject either come to Eugene or Springfield and look into it, or write to us after a brief period, when we expect to get some very definite data, and our company will be very glad to give you any information we have or can get.

W. H. R. Fraser: The largest mill we have connected with our system is probably a good deal smaller than that which Mr. Norman spoke of. The largest mill, I think, has something like 750 to 1000 h. p.; the mill is about nine miles from the nearest substation and is also fed in connection with the same line feeding a town. So this is not a mill line alone, but also a lighting line. We have had no complaint regarding the fluctuation of voltage, so that it cannot have been very bad.

In regard to the utilization of refuse: one mill that I know of has been experimenting with briquets, but whether successfully or not I cannot say. Another mill until recently was trying to produce turpentine from sawdust of certain woods, but that has been a failure.

The question of supplying power to very large mills could scarcely be considered, unless very favorably located. One of the largest mills in the world, for instance, has a total capacity of one and three-quarter million a day; driven by individual units; we could never offer them power at a rate that they could consider in preference to installing their own plant; if we delivered power to them we would have to have a 30,000- or 40,000-volt line installed and substations, and by the time we did that the cost of the power to them would be so great that it would be prohibitive.

Another point: I believe that Mr. Whitney mentioned something about coke. I do not think there is a single sawmill in British Columbia using coke today.

F. D. Weber: I remember seeing a note in some trade journal in which it mentioned that there has been a process devised of drying lumber in the open air by the use of quite an appreciable amount of current at low voltage, by simply stacking and separating the layers of lumber by wet carpets. I would like to know if anyone knows anything further on this subject. I understand that is done in Australia and some places in England. If that is the case it seems to me that would solve the question of the dry kiln.

John Harisberger: I may be a little optimistic in regard to companies operating hydroelectric plants selling power to sawmills to their mutual benefit. On our system in the Puget Sound district, we have several mills which have proved quite satisfactory, from both a commercial and an operating standpoint. We also furnish all the power for two coal mines, amounting to 1100 h. p., and several other mines are considering taking our power. I have had some experience in the early days when attempts were first made to operate sawmill machinery by electric motors. The main difficulty was to get sufficient information so as to determine the proper size motors to install. This is entirely different now, as manufacturers of electric apparatus and central station people have accumulated a great many data on such applications, so that it is no longer a question of experiment.

E. F. Whitney: I am rather disappointed at the lack of optimism; at the same time I am pleased at Mr. Harisberger's expression that he does look forward favorably to the use of central station power in the sawmills. It can be used, and under certain conditions it can be put in and can operate as cheaply as one can generate and supply his own power, but you must first convince yourselves that it can be done and afterwards convince the mill men. There is always the question of cost of installation and cost of operation.

To begin with the cost of the motors: I have recently completed, in connection with a mill architect, two estimates for entirely different types of mills, one a single-band mill and another a double-band mill, together with the planing mill. Complete estimates were made, first, using steam drive, and second, using electric drive, for each type of mill. The electric mill included the necessary generating station, on the assumption that power would be derived locally from mill refuse. We were surprised to find that for the sawmill alone, electric drive proved lower in first cost—installation cost—than steam, and this without including the planing mill. This latter would have made the balance even greater in favor of electric drive. There is no difference of opinion as regards the very much lower operating and maintenance cost of an electrically driven sawmill.

This of course was an individual case and was figured on its own merits. You will have to let by-gones be by-gones and not consider those mills designed and built along the old lines of steam drive with line shafting and belting and motors placed here and there wherever a drive was needed. The mill must, to get best results, be laid out with electric drive in view, and full advantage taken of its flexibility. We now know what can be accomplished, but the results come only after careful and correct installation and not by chance.

A mill requiring approximately 2300 or 2400 h.p. usually has over 20 separate and distinct engines scattered around its plant; it must have high-pressure steam lines to each one of these engines; the largest would be about 800 h. p. and the smallest about 25 h.p. There need be no further comment than that engines used under such conditions are very uneconomical steam users. An item which is lost track of is the boiler capacity that is required to supply such an installation, and the large initial cost and high upkeep cost of the steam-generating equipment. Electric drive would reduce it at least one-half.

Regarding the ability of the motors to stand up to the work: I recall an instance of a blower, with impellers 80 in. on one side and 70 in. on the other, pressed upon the motor shaft extensions. The motor was rated 100 h. p., 720 rev. per min. The motor did the work satisfactorily, but in the course of an investigation just to see how much power the blowers were taking we found that while the blower specifications called for 96½ h.p., 147 h.p. was the output of that motor, day in and day out, ten hours a day, five hours in the morning and then shut down one hour at noon and then five hours in the afternoon. In this case the motor was in at the top in the planing mill, which is always a well-ventilated structure, it had good cooling air, and the working capability of the motor was increased considerably above what might have been found in a more unfavorable location.

With the present successful mills operating with electric drive, with the proposed largest mill on the coast preparing to use electricity throughout, there can be no question as to the economy of this method or the capability of the electric motor to do the work efficiently and successfully.

The point has been brought up that they must always have steam in the mill. Granting that they must have steam for some uses, there is no necessity for them to have the quantity of steam equipment that will be necessary in all cases except with electric drive.

Upon the question of production: This is the one subject which sawmill men are glad to discuss and consider at any length. They appreciate that their only hope of salvation is to cut down their costs of production. I have known many instances of steam-driven mills where the lag in the steam engine during the cut in the main headsaw is as great as 30 per cent. I have seen the edger lag fully as much. That simply means that they are losing so much productive time. This is unknown with motor drive. Practically all of the motors are squirrel cage type—with a few exceptions, such as the one driving the headsaw; the only reason we use a wound-rotor motor there is because of the limited generating capacity in the average sawmill and to limit the current input at starting. Its characteristics are of course practically the same as the squirrel cage motor after it is up to speed, and any squirrel cage motor would absolutely reach its breakdown point before it had any such regulation as that, unless of a special design. The automatic overload protection and ability to stand up under varying load conditions has already been spoken of. This is an important item when we are driving, for instance, a refuse conveyer. That is probably as severe a drive as any in the mill. With steam drive from the main shaft, if the conveyer should stick, as with a slab jammed under the chain, something must break to clear the trouble. This means lost time, and repairs. With electric drive, we might have the conveyer pretty heavily loaded at times, but of course the relay would be set to care for a predetermined overload with a reasonable time limit, and any more severe condition than that for which it is set should trip the motor out of circuit, and relieve the transmission machinery of the severe strain, saving the breakage that would otherwise occur.

The question of maintenance of voltage was touched upon by Mr. Weber; it is one of the most important points in connection with the operation of electric logging engines. The substation must be 200 to 1000 ft. from the location of the engine itself; in the beginning of the operation it may only be 200 ft., but as the work is extended and the donkey gathers the close timber it will probably be, at the next step, 1000 ft. away. The duty is heavy, often requiring the motor to exert very close to its maximum torque, so we must take the precaution to see that good voltage is the rule at the terminals of the motor. This of course applies to sawmill machinery as well, because we cannot get the maximum productivity unless we maintain our speed and capability to care for heavy loads suddenly applied.

In regard to the question of fire hazard and enclosed motors: This is really the reason that squirrel cage motors are so universally used. In such motors the bearings of course are practically the only source of fire risks. The motor bearings should give very little trouble, and after once being in good condition should require very little attention.

Enclosed motors were never seriously thought of. As to the possibility of dust and chips getting in the windings, the ventilating scheme which has generally been adopted in the manufacture of motors is such that the air comes out through the [illegible] of the machine, and will tend to remove any dust that would [illegible], on the chance, get into the windings through them. Of course, it would be possible to cover the [illegible] will be operating. The [illegible] well around any sawmill at the [illegible] that of the [illegible] and any machine [illegible] takes the air hose and blows all the dust and chips away. Where it is necessary to use the slip-ring type of motor, of course the slip rings should be enclosed. There is a possibility of sparking at starting, and until the motor is up to speed, and it is common practise to enclose them.

On the log carriage some slight trouble has been experienced with oil splashing out of the set-works motor bearings. The rate of acceleration of the log carriage at each end of its travel, particularly at the beginning of its return, is very high, but with reasonable precaution, oil-throwing trouble can be remedied. In fact, the first set-works motor used was strictly a standard motor, and no trouble was ever experienced with oil splashing out.

In regard to the load factor of a complete mill, we usually assume the demand factor of an electrically driven mill as 70 per cent, in kilowatts, of the connected load in horse power, and the load factor as about 70 per cent. In other words, if we have 1500 h.p. installed, about 750 kw. would be the average load on the mill. I have detailed records of two complete sawmills in the Northwest. One of them has a load factor of 57 per cent. The demand factor is 83 per cent. The average cut per day is 115,000 ft. b.m. The highest peak recorded in any ten minutes was 1150 kw., and the maximum demand for any ten-minute period was 910 kw. The other is a group-drive mill, with 1300 h.p. connected; the load factor is 65 per cent, and the demand factor 88 per cent. The daily cut is 121,000 ft. b.m. As we would expect with the group drive, a smaller connected load has a larger cutting capacity, the highest peak for any ten-minute period was 1000 kw., the maximum demand for any ten-minute period 850 kw.

The prevailing power factor, I suppose, if we take all of our mills, is roughly 70 per cent; some mills run as low as 50 per cent, some mills run as high as 85 per cent. I have records of a mill which has been in operation for some two years, where power factor throughout the day's operation never gets below 74 per cent, and there are times when it goes up as high as 85 per cent. That is an extremely high point for a typical induction motor load.

The greatest drawback to the maintenance of a high power factor in sawmills is the small number of large motors that must necessarily be used, which, during a great portion of the time, must certainly run at very light load. Though not less than 200 h.p. is required on the average edger, and a motor somewhere in the neighborhood of 250 or 300 h.p. on the head-saw, the loads averaged per day for these machines will be about 50 and 100 h.p., respectively. The great majority of group drive installations are, as a rule, well loaded and run at good power factors and at good efficiencies. The planing mill equipment has a very fluctuating load; during a portion of its load it runs at a relatively low power factor and low load factor. On the average, a mill of about 2100 h.p., such as Mr. Norman spoke of, under general operating conditions will have a load factor varying from 65 up to 80 per cent. The particular mill of which he spoke has 74 motors with a total of 2053 h.p. connected: the sawmill has 52 motors with 1645 h.p.; the planing mill 18 motors, with 340 h.p. The daily kilowatt-hour consumption had been estimated at from 7500 to 8000 kw-hr. With operations well under way, these figures were confirmed.

As regards the cost of wiring a sawmill installation, that depends largely on the individual. A mill man can put in a wiring job that will equal or excel that in any high-class city office building, or he can put in simply a substantial wiring job that will be satisfactory for his service. There is a difference in cost of, I suppose, 250 per cent. In making up the comparative estimates that I have already spoken of, for steam drive and electric drive, these estimates were based on giving the electrical installation the worst of it in every case that we possibly could, and so we figured on conduit wiring throughout. Even then the wiring cost amounted to about $5500, I think. We had about $9000 which we could have used for this and still come out equal to steam drive.

The fire hazard in the logging industry is something that would have to be given consideration. That, of course, is always brought up whenever the subject is broached to loggers. There is no reason why electrical equipment that is operating a logging camp cannot be as cheaply and as safely handled as it can be in any of our generating stations. The transmission line usually runs along a railroad right-of-way and is just as well protected as any other power company's transmission lines. From it branches are run, depending upon the size of the company's operations; from the substation an armored cable leads out along the ground to the logging engine itself; the cable used is typical submarine cable, which is perfectly safe.

In regard to the question of electric drive for the log carriage: Suppose, for instance, we look at the typical operating cycle of a log carriage given on page 1331. Even with a log of only 1500 ft. b.m. you have a total weight of 38,000 lb., about 19 tons; the requirements of mill operation do not allow the carriage to lag any more than is necessary, and the average speed is about 250 ft. per min. in the cut. That is based, of course, on a single-cutting band mill. The average speed of return is about 650 ft. per min., and we must accelerate that outfit to that speed and maintain it at least for a portion of the travel of the total distance, varying, say, from 40 to 50 ft. as an average. There is not much travel but it is high-speed work, the acceleration is fast—in fact it is all that a person can do to stand on the log carriage and maintain his balance. A log of 1500 ft. b.m. is by no means the heaviest load, it is about an average. If we should get a log of about 5000 ft., or about 40,000 lb., on, it would run the total weight up to something over 35 tons that must be handled at this speed. The common method is by a twin-cylinder, simple steam engine, which operates a drum. The engine, complete with its equipment installed, costs about $3000 to $3500. Any electrical scheme that can compare favorably with it in first cost and in ultimate cost, including operation, will undoubtedly meet with favor from the sawmill people. They would like to do away with the engine, but nothing to compete with it has been shown up to the present time.

The coal and other fuel costs as given on page 1320 applied to logging, not to sawmill operation. In the logging industry they have realized they were burning good merchantable timber as fuel, as the logs cut up and burned under the donkeys must be the very best or they will not split, and on account of the grade of timber they have to use, they have attempted to use oil and coal. Some camps have run comparative outfits to get data on the results accomplished by the use of the various fuels.

In regard to Mr. Fisken's suggestion that additional uses for the refuse be given, and that nothing be said about burners: I attempted to take the point of view of the man who was fully informed about the electrical side of the question but knew very little of a sawmill or its workings. Of course it is necessary for the sawmill operators to dispose of the refuse, because there is too much of it for their own power demands, and this must be got rid of in some way. Usually it is burned in the burners, and they are a source of expense.

I have touched upon the load of the whole mill. I might say that the two cases cited applied to fir districts. In pine districts the load is very much lighter, the connected horse power, we will say, in one case, being 1900 h.p., the load factor only 46 per cent and the demand factor 67 per cent, an average daily cut of 350,000 ft., with a maximum demand for ten minutes of 800 kw. and the highest peak in any ten minutes 950 kw. That is in marked contrast to the greatly increased power demand with smaller cut of the larger fir mill.

Attempts have been made to produce some sort of load equalizer, but only for some individual machines. The fluctuations are not at all regular; they might last for prolonged periods, or might come in quick succession during one or two hours of operation, and might be very infrequent at other times. The demand question must be solved by those desiring to obtain the sawmill load, for its character is to a certain extent fixed.

In the case of the edger there is a machine with no flywheel effect whatever, a simple arbor with five to seven or eight saws, and it is operated by a motor of large capacity. Its highest load comes on instantaneously just as soon as the cant is started through the edger and it lasts until the cant has finished its travel and the cut has been made, seven to ten seconds. Those saws operate at a rim speed of 9000 to 12,000 ft. per min. and at speeds of 1200 to 1800 rev. per min. Any weight that could be added on the shaft of the edger would have to be of such small diameter and great length, to be within the safe limits of even the strongest materials, that it would run the cost up to too large an amount and take up too much space.

These loads are and have been well appreciated by sawmill operators. The operator lays out his plant to care for them. He knows the capacity plant required to care for the load, and in reality the effect of these fluctuations is not to increase the capacity of the equipment which it is necessary for him to have if he is going to generate his own power, and if they do not increase his own capacity why should he spend money to make it a more favorable market for the central station man? That is also the reason why efforts have not been made to obtain a better power factor. Of course it could be obtained, could be done by installing synchronous machinery.

The generating station—isolated or not—must for such a load have an automatic voltage regulator system, or they cannot expect to accomplish the results which they had anticipated with the electric drive. In operating at say 480 volts at the generator, which is a common voltage, it is exceptional to see the voltage drop below 460. Even with the severest load, such as the starting of the band headsaw, or the edger motor, there is a voltage drop, but it is instantaneous, the voltage going right back to normal again, and under running conditions you very seldom see a fluctuation of the voltage greater than one or two per cent at the outside.

In regard to the use of the refuse for briquets and turpentine, I referred on page 1353 to the experimental use of briquets for paving purposes: "Attempts have been made to use sawdust from Pacific coast mills, which cut mostly fir, spruce, and hemlock, for manufacturing wood alcohol and ethyl alcohol. In practise, however, the manufacturing costs run so high that it has proved unprofitable. The latest projected use is in making sawdust briquets to be used for paving purposes. Such a plant has been completed, although its operations have not extended over a sufficient period to determine the ultimate success." There have been several such attempts made, none of which has proved successful up to the present time, so far as I know.

It would be well to compare the use of the refuse for fuel for a steam generating station, in connection with a large power system, with the development of remotely located water powers. That would open up a field for power installations for the power company which in some cases they could not expect to get otherwise, because of the equipment already installed by the milling company.

I have heard some mention of the electrical drying scheme spoken of by Mr. Weber. I believe that was touched on briefly in *The Timberman* about two months ago. I have heard no comments on its real success.

An interesting feature of the mill spoken of by Mr. Harisberger is that it was the first case of which we have record where the headsaw was direct-connected to a driving motor. They had a double circular headsaw in this particular mill, the lower saw connected directly to the motor and the top saw belted from the lower one; the operation was entirely satisfactory—in fact, it is to be recommended, with proper precautions taken. The log carriage also was driven by a motor. I do not know the particular scheme that was used, but it was not entirely successful from the point of view of sawmill operation, because it did hold back production. Mr. Harisberger said that none of the Everett sawmills is completely operated from central station power. There are two completely electrically operated mills in Everett, however, with a third, the largest on the coast, under construction.

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THE ELECTRICAL OPERATION OF THE BUTTE, ANACONDA & PACIFIC RAILWAY

BY J. B. COX

Abstract of Paper

Of a total of ten notable instances of steam railway electrification in this country, the Butte, Anaconda & Pacific was the first if not the only one in which the prime cause for the change in motive power was an expected decrease in operating expenses sufficient to give immediately a satisfactory earning on the new investment of capital required for the improvement.

The preliminary investigations and estimates had indicated a probable annual saving amounting to about 17.5 per cent on the total investment, of which 11 per cent was expected to result from the partial substitution of electrical energy, costing about 0.552 cent per kw-hr. at the secondaries of the substation transformers, for coal of 12,250 B.t.u. calorific value and costing $4.25 per ton delivered. The remaining 6.5 per cent was expected from reduced cost of locomotive maintenance, engine house expense and enginemen's wages.

On this prospect, an expenditure of $1,201,000 was made in the electrification of 90 miles of track and in replacing 22 steam locomotives by 17 electric locomotive units which now operate about 80 per cent of the total locomotive-miles.

The actual results as indicated by the first six months of full electrical operation show the total net saving in operating expense to be at the rate of $242,299.12 per year or an earning of 20.02 per cent on the investment, of which the decrease in the cost of coal and power is 12.5 per cent.

Other savings are due to decreased cost of locomotive maintenance, engine house expenses, lubricants, supplies and trainmen's wages.

The average tons per train hauled by the electric locomotives has increased 33 per cent, the average time per trip decreased 30 per cent, the delays to traffic decreased 41 per cent, the number of trains decreased 25 per cent and the number of engine and train crews decreased 25 per cent.

THE AUTHOR wishes, at the outset, gratefully to acknowledge the assistance of Mr. H. A. Gallwey, general manager, Butte, Anaconda & Pacific Railway Company. It is through his coöperation and effort that the operating data given herein are made available. Information of this character has seldom been published and that it is here given to the public is a tribute to the broad-minded policy of the railway company.

The Butte, Anaconda & Pacific Railway was built in 1892 principally for the purpose of conveying the ore from the mines at Butte to the Washoe smelter which had been located at Anaconda, 26 miles west of Butte, where an abundant supply of water, so necessary in the reduction of the ore, was obtainable. The tracks connecting Butte and Anaconda constitute the main line, which is approximately 25.7 miles in length. As the mines are mostly around the top of Butte Hill and the shafts through which the ore is hoisted to the surface are scattered over a considerable area, yards were built at a convenient point on Butte Hill for the concentration of the cars containing the ore from these shafts, as well as to serve as a distribution point for the supplies to the mines, and a branch locally known as the Missoula Gulch line, Fig. 3, was built from these yards to connect with the main line at Rocker, where yards were also established.

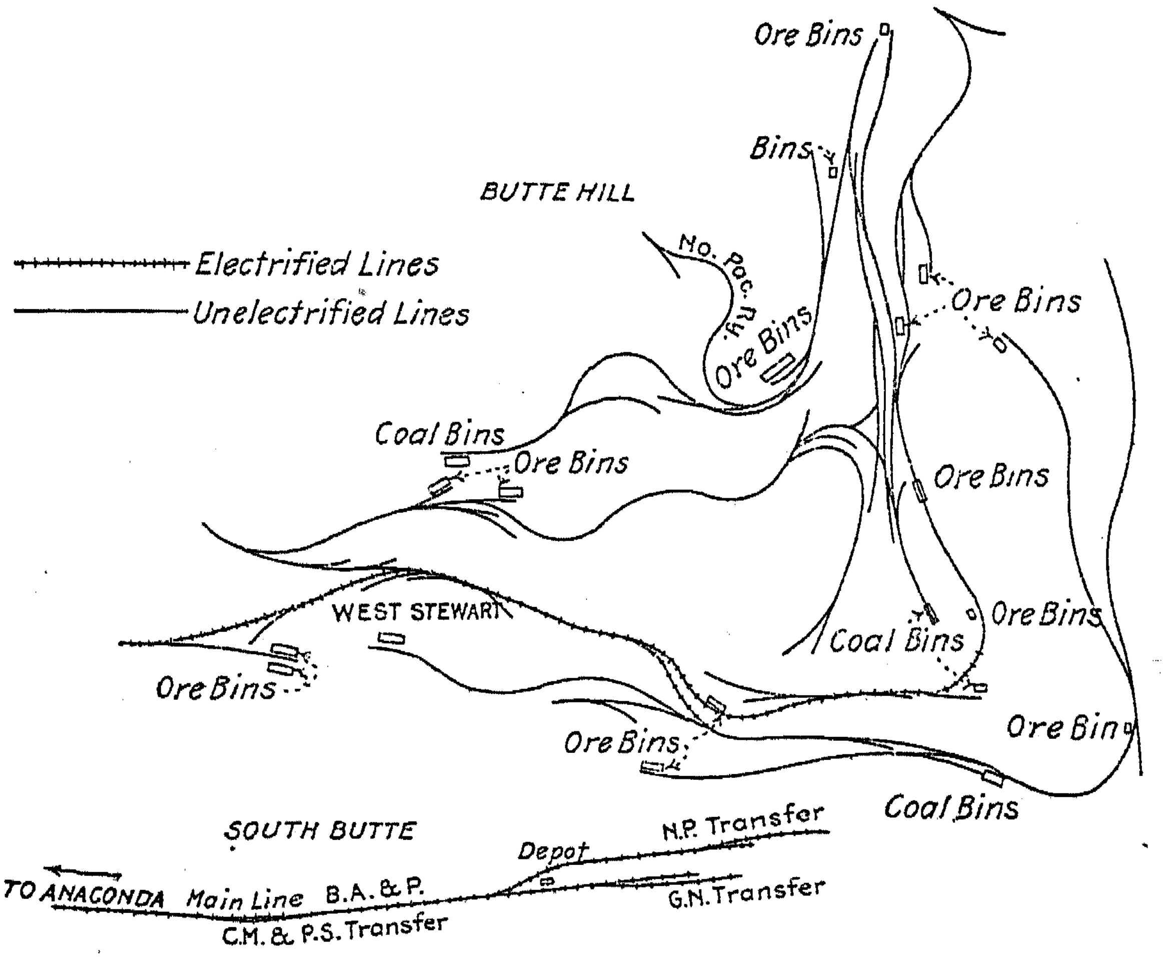
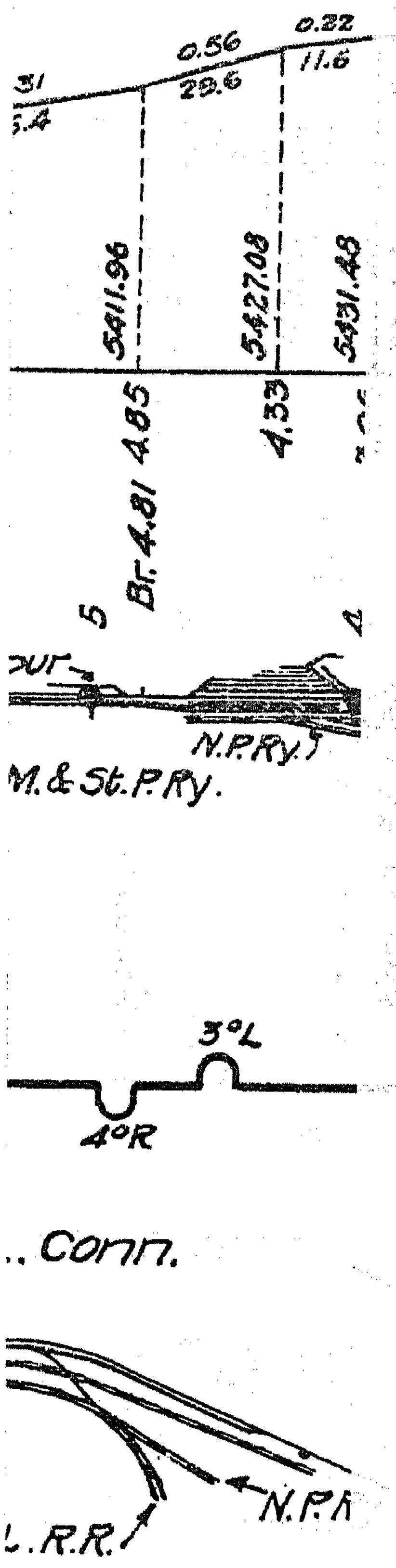


FIG. 2—OUTLINE MAP OF RAILWAY LINES ON BUTTE HILL FOR COLLECTION OF ORE AND DELIVERY OF SUPPLIES

Since the concentrator at the smelter is also on a hill at an elevation of approximately 340 ft. above the main line, it was advisable to establish another yard at East Anaconda from which to distribute the ore and other supplies to the different centers on Smelter Hill. The lines from these yards at East Anaconda to the smelter are known as the Smelter Hill lines, the longest branch of which is that leading to the concentrator, which is about 7¼ miles in length. Two spurs lead off from this main track, one to the stock bin yards and the other to the copper tracks, Fig. 4.



31
5.4
0.56
28.6
0.22
11.6
5411.96
5427.08
5431.48
Br. 4.81
4.85
4.33
5
4
Spur
N.P.Ry.
M.& St.P.Ry.
3°L
4°R
.. Conn.
N.P.
L.R.R.

From the Butte Hill yards spur tracks radiate about Butte Hill to the shafts of the various mines and other points where supplies are to be delivered, Fig. 2. Bins for receiving ore as it is hoisted from the mines are located near each shaft and from these bins the ore is loaded into hopper-bottom steel ore cars of 50 tons capacity each, these loaded cars being delivered to the Butte Hill yards, where they are made up into trains and taken down to the Rocker yards, where they are made up into still larger trains and taken over the main line to East Anaconda yards. Here the trains are broken up to be transported in smaller units up Smelter Hill to the concentrator yards. Thus practically all of the ore cars are handled by five different engine crews between the ore bins at the mines and the receiving bins at the concentrator.

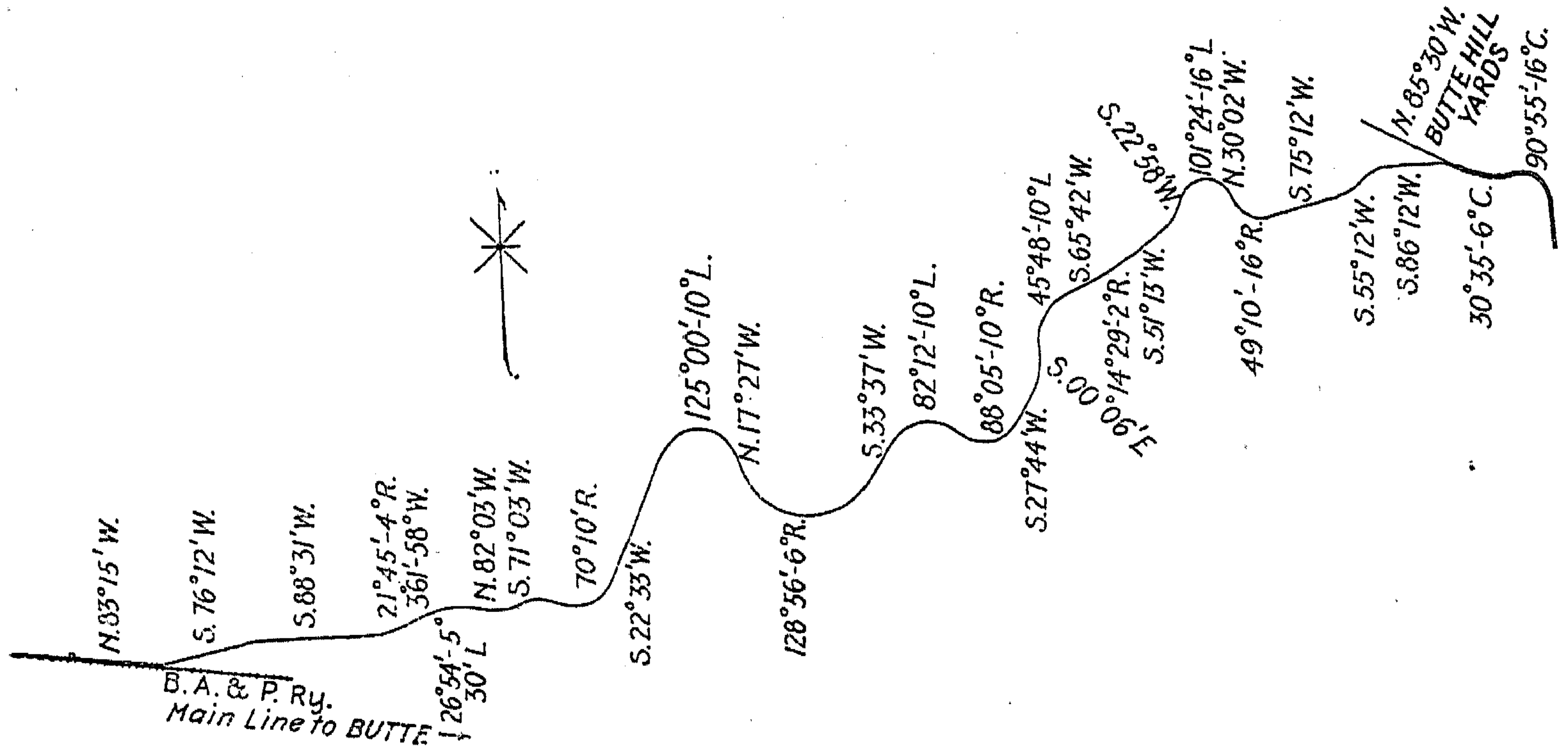


FIG. 3—MAP OF MISSOULA GULCH LINES, ROCKER TO BUTTE HILL YARDS, BUTTE, ANACONDA AND PACIFIC RAILWAY

A total of 27 steam locomotives was owned by the railway company, classified as follows:

Switching	7
Consolidation	8
Mastodon	10
Passenger	2

The coal used on the steam locomotives was obtained from the mines at Diamondville, Wyoming, and had to be transported approximately 395 miles for delivery to the bins of the railway company, at which point its average cost was approximately $4.25 per ton.

The machinery at the mines and the smelter had mostly been electrified, and the results had been so satisfactory that the railway company had a study of their conditions made for the purpose of investigating the advantages that might be expected from the electrification of their lines, the result of which was the placing of a contract in December, 1911, for the electrical equipment of the main portion of its line, consisting of the main line, spurs and yards between Butte and Anaconda, the Missoula Gulch line between Rocker and Butte Hill yards and the Smelter Hill lines. Owing to local conditions on the spur tracks leading to the various mines from Butte Hill yards, it was thought advisable not to electrify these until a later date.

Three of the steam switching locomotives listed above were used daily on Butte Hill collecting ore from and delivering supplies to the various mines from the Butte Hill yards.

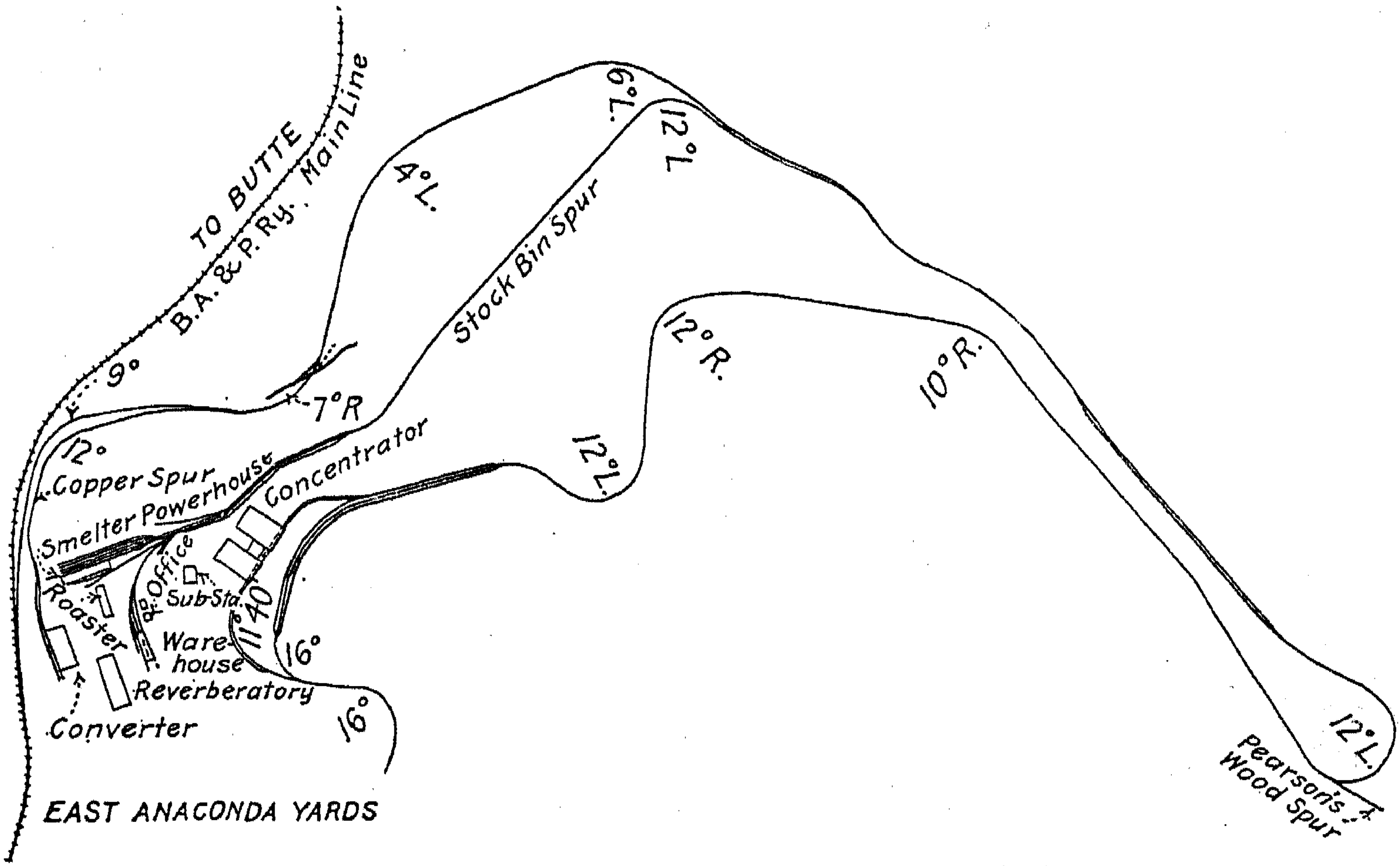


FIG. 4—MAP OF SMELTER HILL LINES, BUTTE, ANACONDA AND PACIFIC RAILWAY

The Georgetown extension to Southern Cross, 22.9 miles west of Anaconda, was underway at the time, but as it was expected that a few trains per week would take care of the traffic over this branch for some time, its electrification was not seriously considered in the original study.

It is fair to assume that a vital consideration leading to the electrification of this railroad was the rapid development and physical consolidation of a network of hydroelectric power plants in the territory tributary to the railroad.

A contract for the power for the operation of the road was made with the Great Falls Power Company, which, operating under the same management and in physical connection with the system of the Montana Power Company, was enabled to guarantee an ample supply of power at all times with exceptional freedom from interruptions to service, and at a reasonably low price.

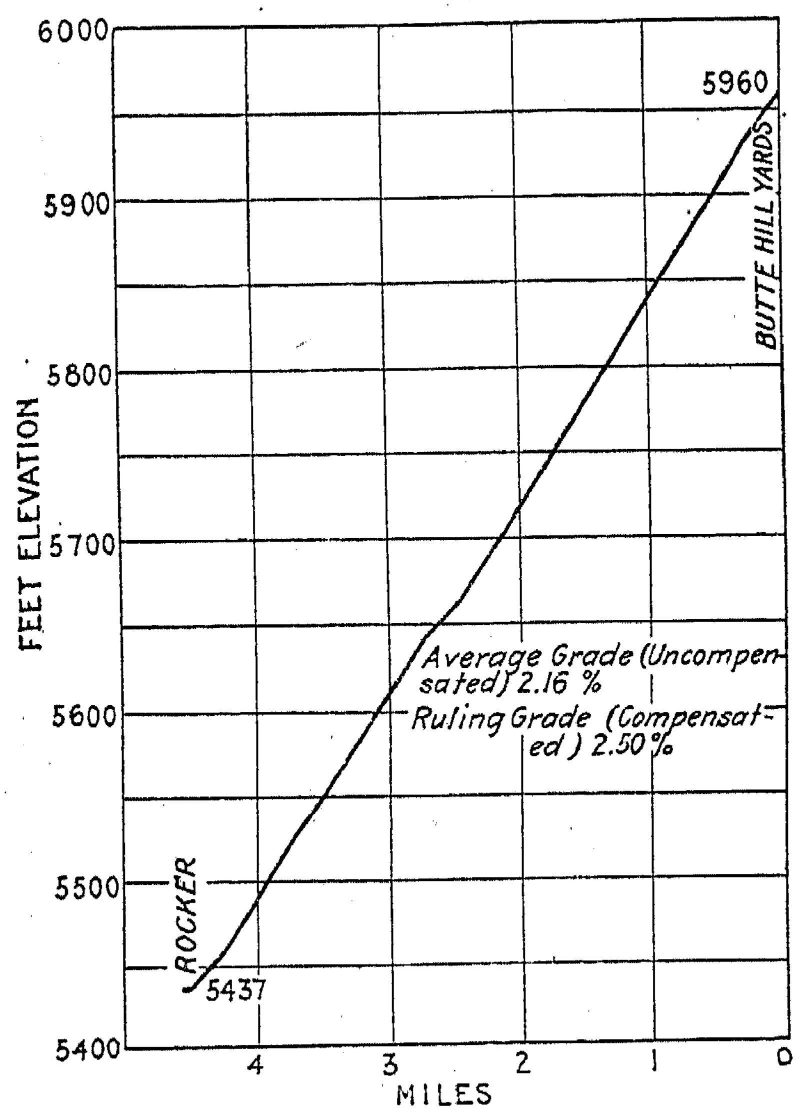


FIG. 5—CONDENSED PROFILE OF MISSOULA GULCH LINE

The tracks recommended to be electrified totaled approximately 90.5 miles, all of which are supplied with power from two substations, one being located in the Missouri River Power Company substation on Butte Hill and the other in the substation building on Smelter Hill, from which electrical power for operating the machinery there is distributed. At each of these substations there was vacant space for the location of the extra apparatus required for the operation of the railway, and the transformer capacity already installed at each place was sufficient to meet the extra demand required for the operation of the railway.

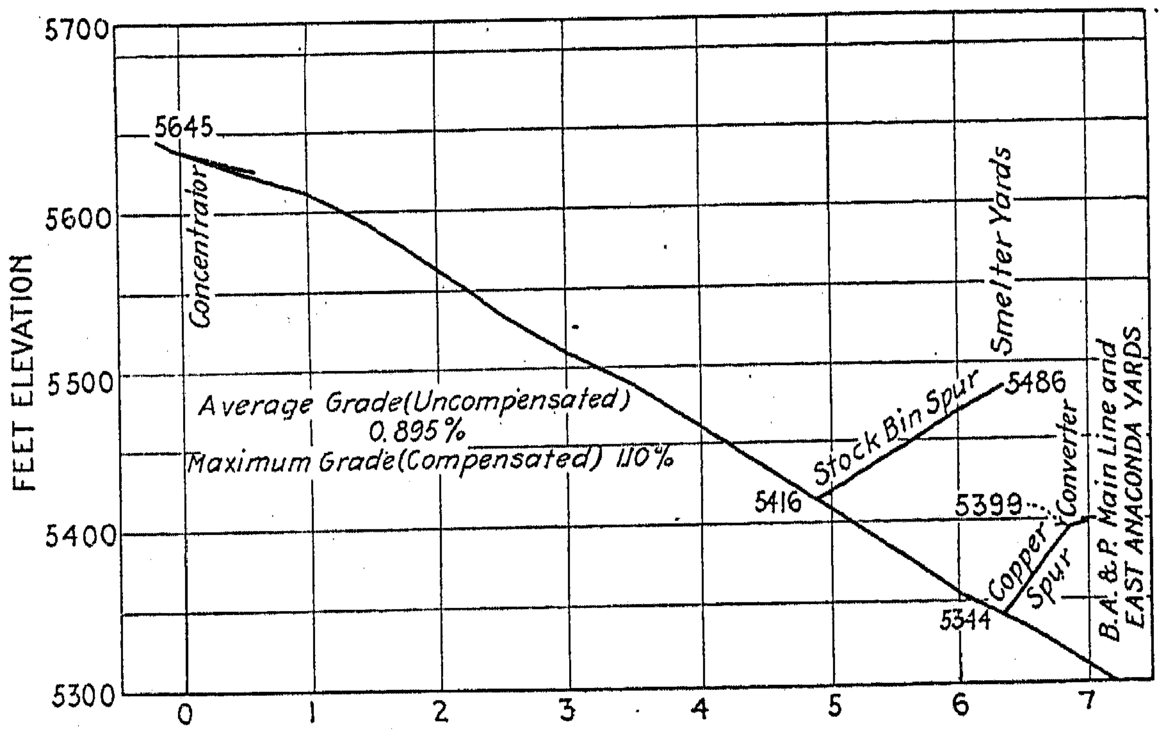


FIG. 6—CONDENSED PROFILE OF SMELTER HILL LINES

The Anaconda substation is connected with the Butte substation by three high-tension trunk lines. The Butte substation receives power over five separate transmission lines from six hydroelectric stations of the following rated capacities:

Big Hole	Development	3,000	kw.	60	ft.	head.
Madison River	“	9,000	“	110	“	“
Canyon Ferry	“	7,500	“	35	“	“
Hauser Lake	“	14,000	“	60	“	“
Black Eagle	“	3,000	“	44	“	“
Rainbow	“	21,000	“	110	“	“
	Total	57,500	“			

There is also now under construction the Great Falls Development, 60,000 kw., 155-ft. head. (Fig. 7.)

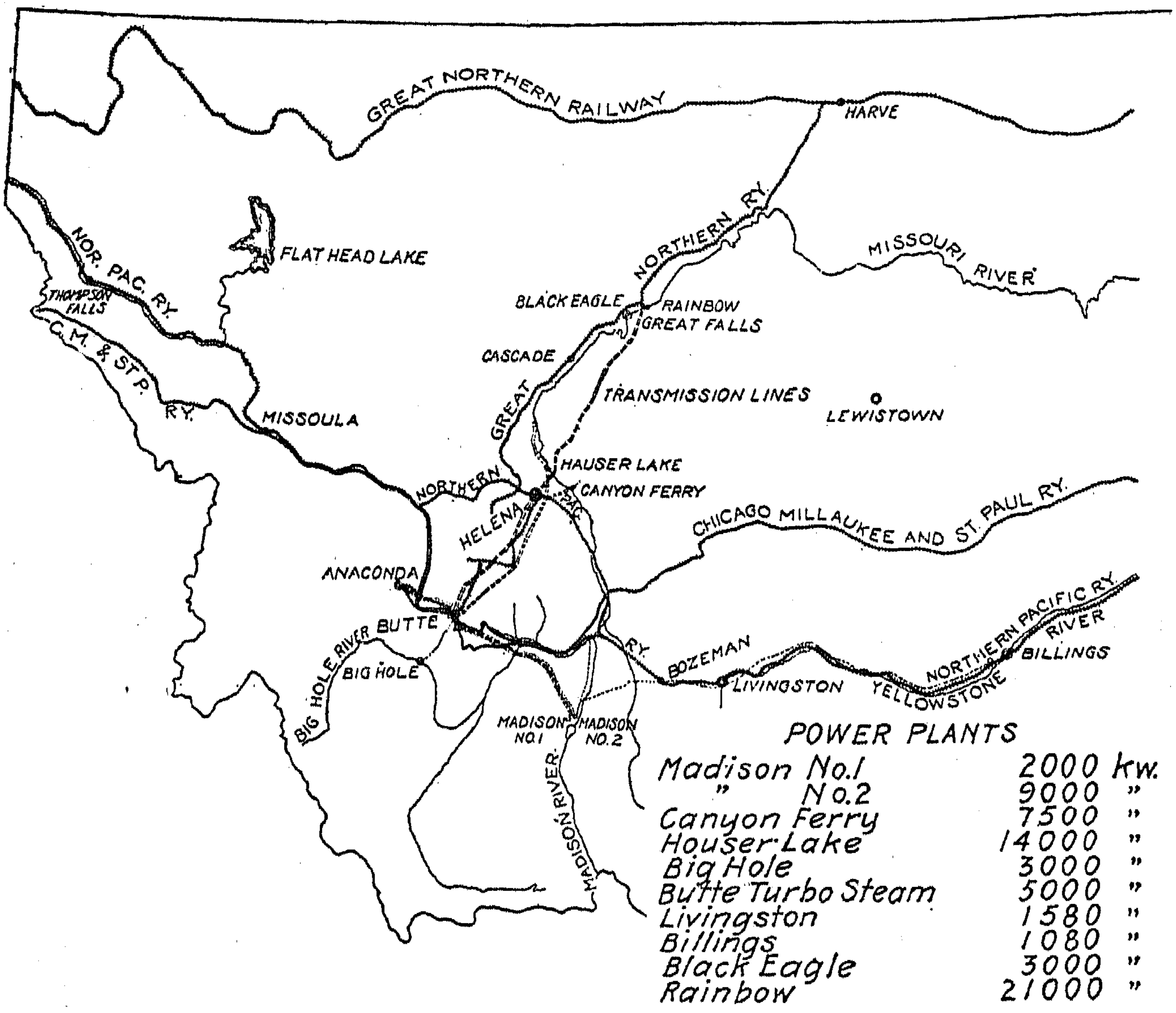


FIG. 7—PLANTS FROM WHICH ELECTRIC POWER IS PURCHASED BY THE BUTTE, ANACONDA AND PACIFIC RAILWAY.

All these plants are on the Missouri River water shed, all operate with free interchange of power, and all, except the first, are located in a series below the new Hebten reservoir, now being completed on the head waters of the Madison river, with an available capacity of 300,000 acre-ft. of storage.

The individual plants are also provided with storage reservoirs aggregating 125,000 acre-feet of total available storage capacity. All of these reservoirs operating under one control are capable of developing from stored water alone, in addition to the power otherwise available from the natural flow of the river, the equivalent of about 100,000 electrical horse power for a period of 100 days.

In view of this development, the generally recognized advantages of purchasing electric power from a large operating system instead of developing the required power independently were readily apparent in the case of the B. A. & P. railway. The railroad was relieved of all first cost of development and transmission of power and of all operating expense up to the point of delivery of power to the two substations. The cost of the delivered power is less than it would have been from an independent development, because the power company is enabled to operate large generating stations at relatively high load factor (about 75 per cent), whereas an independent plant purely for the operation of the railway would have to operate in this case at about 30 per cent load factor, with correspondingly high fixed and operating charges per kilowatt-hour actually used. The large number of generating stations and complete network of transmission lines already developed by the power company afford ample insurance against interruption to railroad service due to possible failure of any part of the generating or transmitting system of the power company, and the enormous inertia or flywheel effect of the motor loads connected to the power system maintain extremely steady speed and voltage under the most extreme variations of load on the railroad.

The original equipment of each substation was practically the same, consisting of two 1000-kw., three-unit motor-generator sets with the necessary starting and operating devices. Each motor-generator set consists of a 1450-kv-a., three-phase, 60-cycle, 720-rev. per min. synchronous motor coupled direct to two 500-kw., 1200-volt direct-current generators, one at either end, the two generators operating in series and supplying 2400-volt direct current to the trolley lines. The generators are compound-wound and have compensating pole face windings as well as commutating poles. The series fields are connected on the grounded side of the armature, while the main fields are separately excited from a 125-volt circuit. The motor-generator sets are capable of carrying overloads up to three times normal load momentarily, and 50 per cent overload for two hours. The value of this characteristic will be appreciated when it is noted that each electric locomotive unit has a continuous rating of approximately 900 kw., almost equal to that of a single motor-generator set, and frequently 16 of the

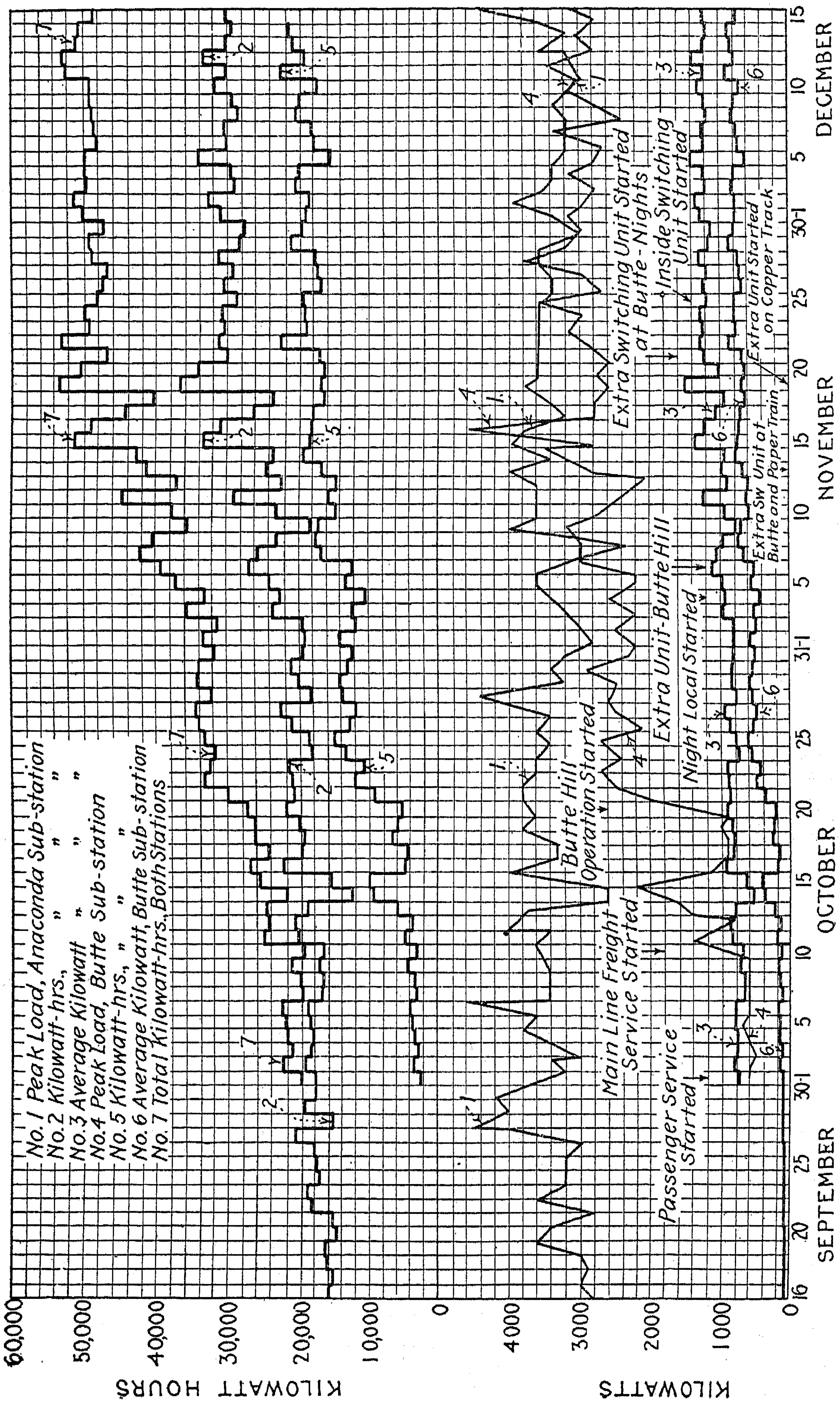


FIG. 8—DIAGRAM SHOWING SUBSTATION LOADS

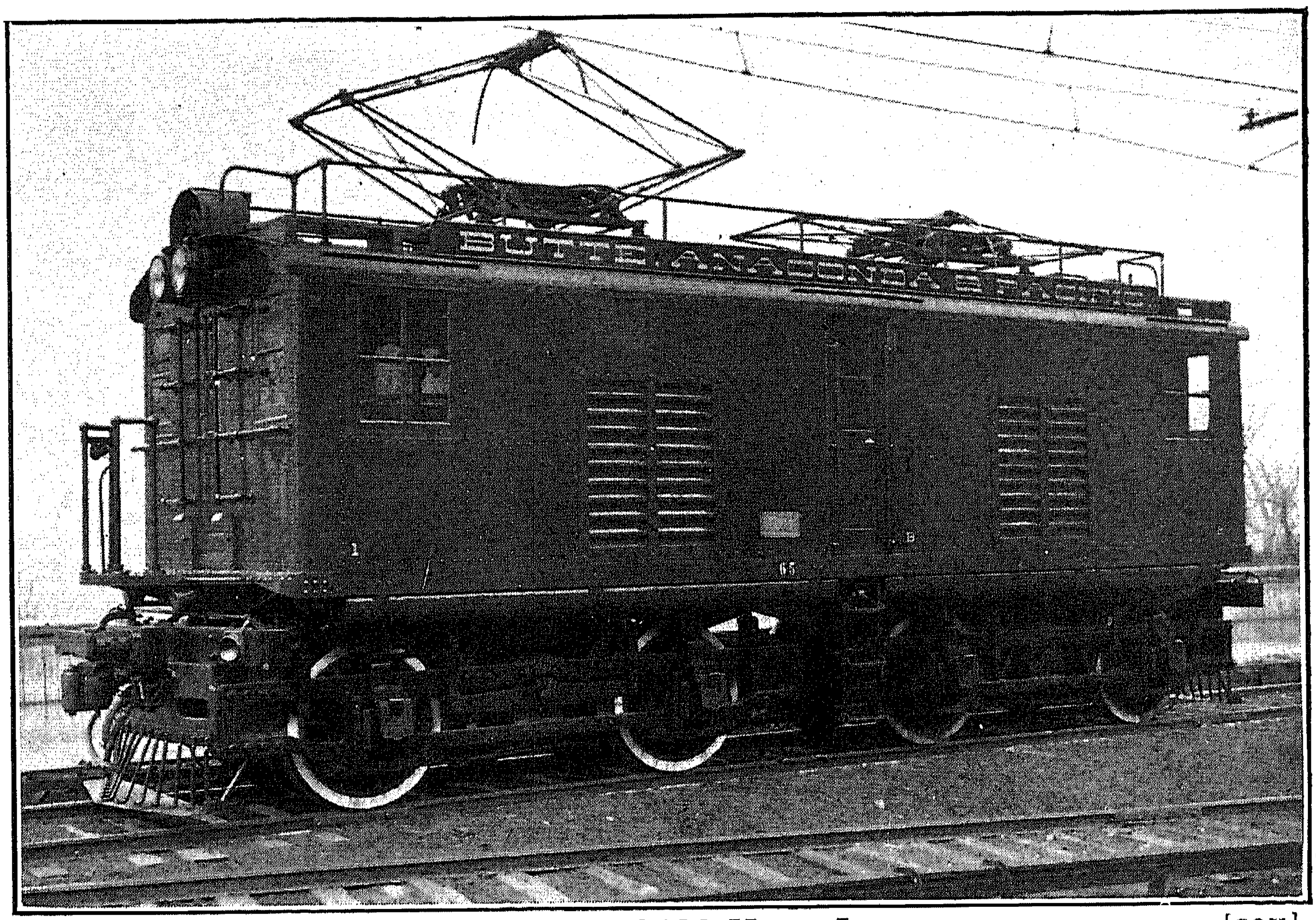


FIG. 9—EIGHTY-TON, 2400-VOLT LOCOMOTIVE [COX]

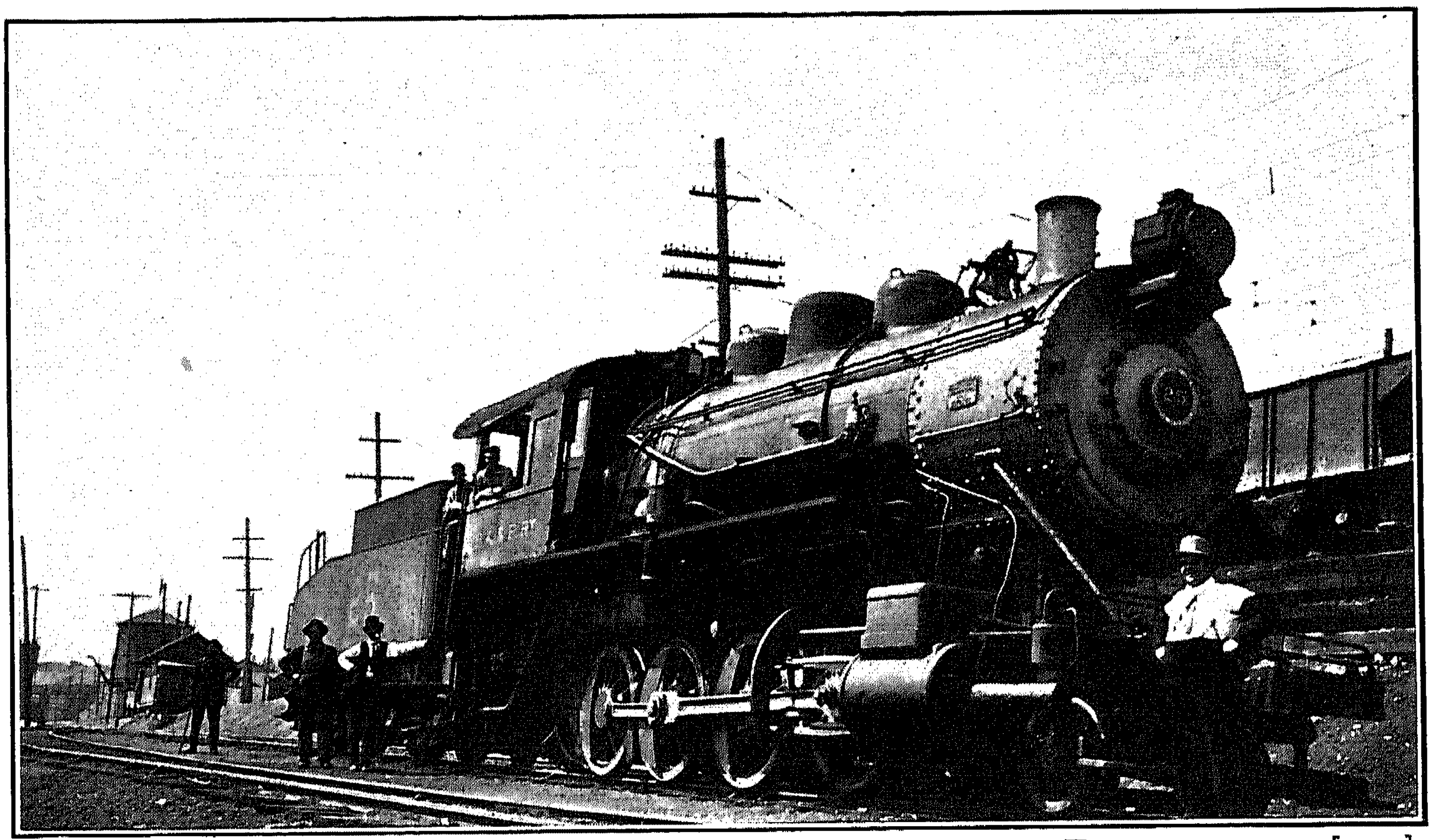


FIG. 10—TYPE OF STEAM SWITCHING LOCOMOTIVE FORMERLY USED ON BUTTE HILL [COX]

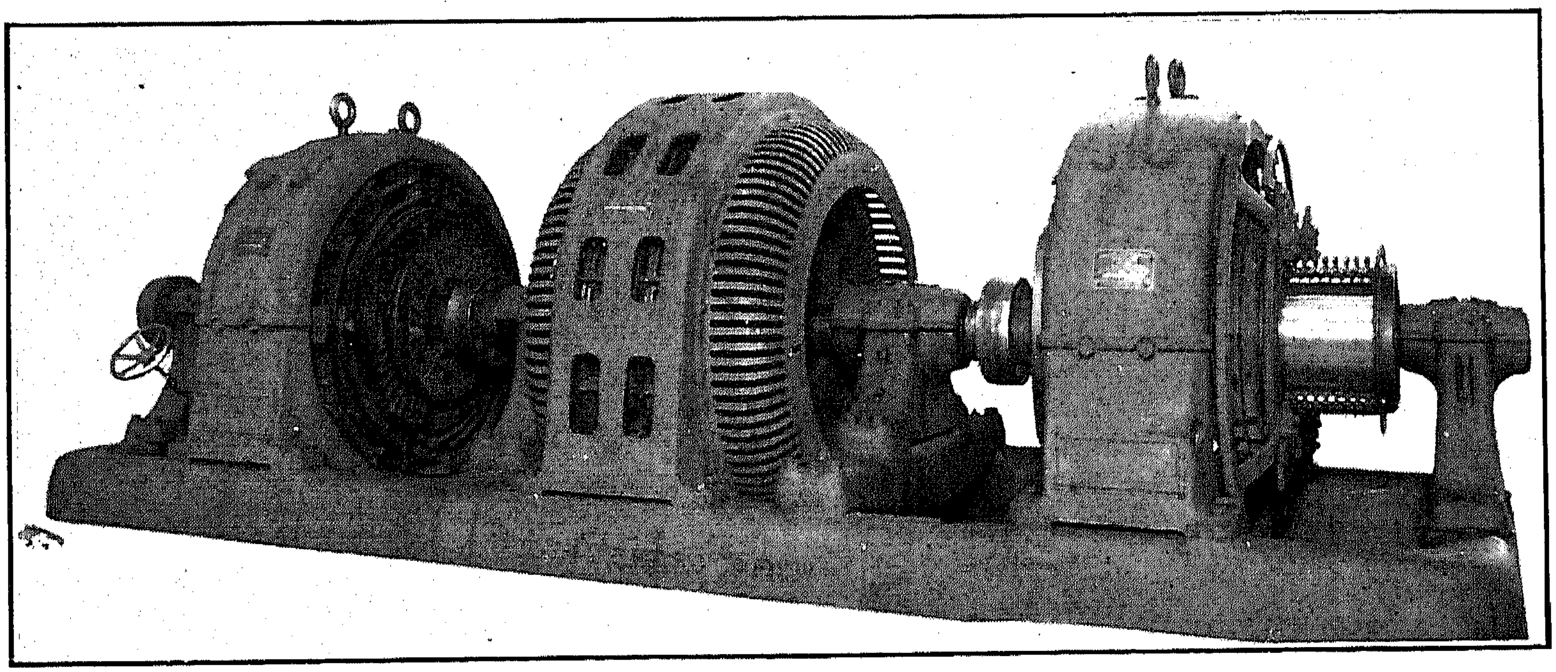


FIG. 11—2400-VOLT MOTOR-GENERATOR SET CONSISTING OF ONE 1450-KV.A., 2300-VOLT 60-CYCLE SYNCHRONOUS MOTOR AND TWO 500-KW., 1200-VOLT, D-C. GENERATORS IN SERIES

17 units are in service simultaneously, 11 of which are concentrated at the Anaconda end at intervals.

Seventeen 80-ton electric locomotive units were purchased, originally, fifteen of which are being operated in freight service and two in the passenger service. These units are practically interchangeable, with the exception of the gearing, the passenger locomotive being geared to operate normally at 40 or 50 mi. per hr. while the freight locomotives are geared to operate at from 15 to 25 mi. per hr., the maximum free running speed being approximately 35 mi. per hr. The continuous tractive effort of the freight units is 25,000 lb., at 15 mi. per hr., but they are capable of exerting a maximum tractive effort of 48,000 lb. for five-minute intervals, based on a coefficient of adhesion of 30 per cent.

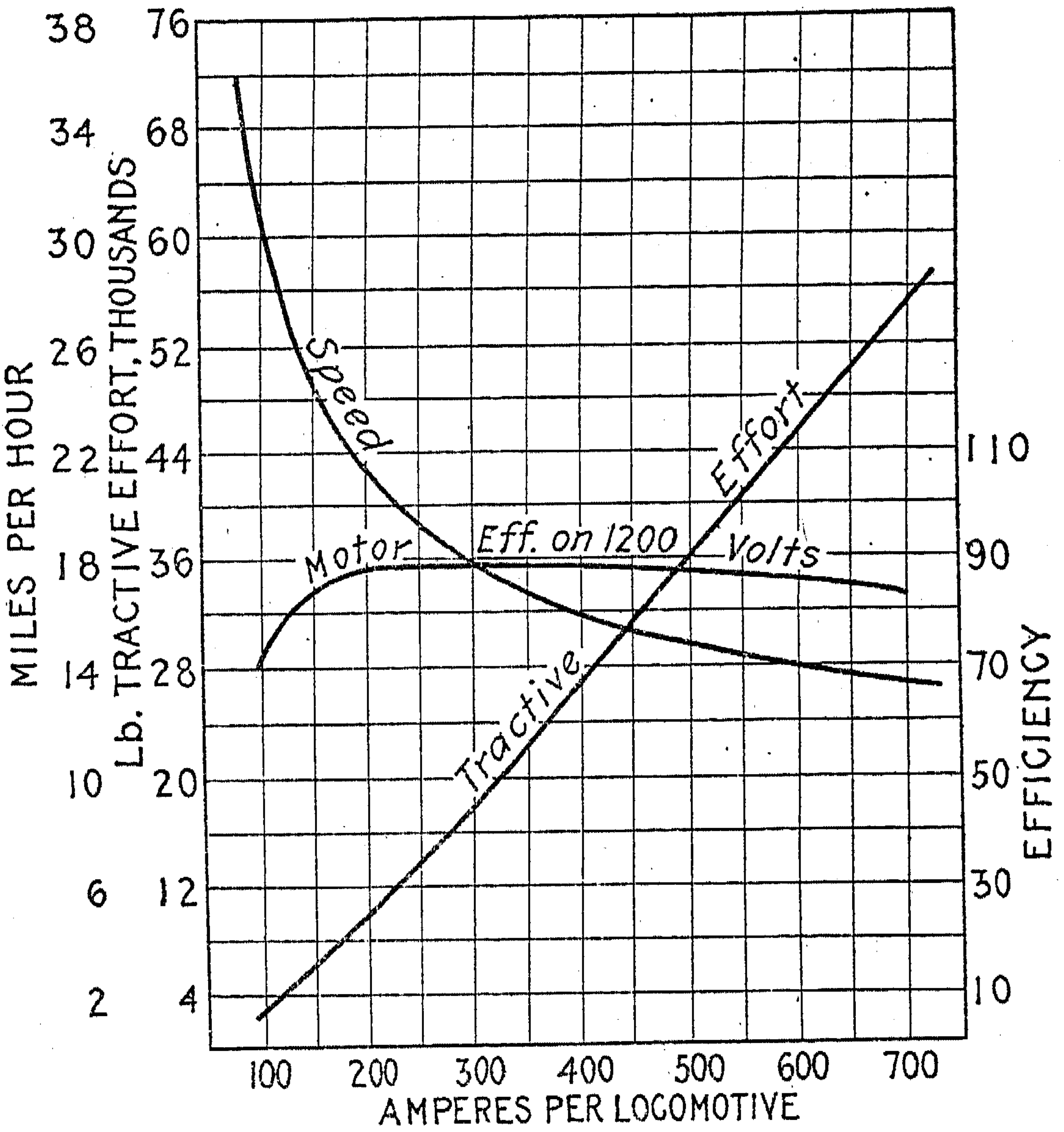


FIG. 12—CHARACTERISTIC CURVES OF FREIGHT LOCOMOTIVES

All the locomotive units are of the articulated, double-truck type with twin gears mounted on projections provided on the wheel centers for the purpose, and in general mechanical design are similar to the electric locomotives in operation on the Great Northern railway, the Detroit River Tunnel railway and the Baltimore & Ohio railway. Each unit is equipped with four commutating-pole motors wound to operate at 1200 volts each, but insulated for 2400 volts, so that two are connected permanently in series and the four arranged in pairs, thus securing the usual two running points, with the difference that on the series position all four motors are in series, and in multiple the two pairs are connected in series-parallel.

The standard rating of each motor is approximately 300 h.p., making the hourly rating of each locomotive unit about 1200 h.p. The control equipment is of the multiple-unit type and provides a total of 19 steps, ten of which are in series and nine in series-parallel. The 2400-volt contactors, switches, fuses, etc., are located in enclosed compartments where they can be reached only by deliberate effort. The current for the operation of the control equipment, the air compressor, and the lights on the locomotive as well as the lights on the passenger coaches, is supplied by a 2400/600-volt dynamotor located in the main compartment of each locomotive unit.

A blower is direct-connected to the armature shaft of this dynamotor which provides artificial ventilation for the main motors and the rheostats. The principal data and dimensions pertaining to the electric locomotives are as follows:

Length inside of knuckles	37 ft.	4 in.
Length over cab	31 "	
Height over cab	12 "	10 "
Height with trolley down	15 "	6 "
Width over-all	10 "	
Total wheel base	26 "	
Rigid wheel base	8 "	8 "
Track gage	4 "	8½ "
Total weight	160,000 lb.	
Weight per axle	40,000 "	
Wheels, steel tired		46 "
Journals	6 "	13 "
Gears, forged rims, freight locomotives	87 teeth.	
Gears, forged rims, passenger locomotives	80 "	
Pinions, forged, passenger locomotives	18 "	
Pinions, forged, freight locomotives	25 "	
Tractive effort at 30 per cent coefficient	48,000 lb.	
Tractive effort at one hour rating	30,000 "	
Tractive effort at continuous rating	25,000 "	

Work on the electrification began in the spring of 1912, and the first electric locomotive was run in Anaconda on May 14th, 1913, about a year later.

On May 27, two ore trains were hauled up Smelter Hill on trial trips with electric locomotives and on the following day a double-unit electric locomotive took over the regular day service of hauling the ore from East Anaconda yards to the concentrator yards, the distance between which is approximately seven miles, the ruling gradient being 1.1 per cent compensated, and the grade fairly uniform through the entire distance, Fig. 6. The steam locomotives used in this service were of the Mastodon type, weighing 108 tons, 83 tons of which was on the drivers. The weight of the tender loaded was approximately 55 tons, making the total weight of locomotive and tender about 163 tons, which would average closely to the weight of the double-unit electric locomotive superseding it. The steam locomotive made ordinarily six round trips per shift, hauling 16 loaded ore cars per trip, equaling 96 cars per shift.

The average time for the trip from East Anaconda to the concentrator yards with 16 loaded cars for the steam locomotive was about 45 minutes. The double-unit electric locomotive began taking only 16 cars per trip but made 8 trips per shift, delivering 128 cars per shift. The average time for the uphill trip with the electric locomotive was about 22 minutes, or approximately half the time required by the steam locomotive for the same number of cars. Empty cars were taken to East Anaconda on the return trip which, being all down grade, gave the electric locomotive no decided advantage, as the speed in either case was limited to about 25 mi. per hr. for safety, on account of the curves in the line. The number of cars hauled per trip was kept the same with the electric locomotives in the beginning as it had been with steam, as it had been decided to make the change-over by gradually replacing one steam locomotive at a time with an electric, taking the engine crew off the one and placing it on the other, thus breaking them in on the electric locomotives in regular service.

One of the regular steam engineers had been given special instructions on the electric locomotives during the experimental running in order that he might become competent to act as instructor to the other engineers until they were sufficiently familiar with the electric locomotives to be left alone.

The load per trip in this service was gradually increased from 16 cars to 25 cars, which is to be the standard for the present. The average time for the up-hill trip with 25 cars is about 26 minutes so that eight trips per shift are easily made, making a delivery of 200 cars possible or an increase of slightly more than 108 per cent over what had been possible for the same crew with steam locomotives. These loaded ore cars average from 70 to 72 tons each, making the trailing load for a 25-car train from 1750 to 1800 tons.

On arrival at the concentrator yards the ore trains are taken by a switching engine called the "spotter", which places one car at a time over the weighing scales, after which they are re-arranged for placement over the concentrator bins from which the ore is fed by gravity to the crushers.

On June 20th this spotting service was taken over by a single-unit electric locomotive and on July 2nd the night service up Smelter Hill was taken over by the double-unit electric locomotive. The steam locomotive used for the spotting service was of the consolidation type and weighed 93 tons, 83 of which was on drivers, the tender weighing loaded 62 tons, making the total weight of engine and tender 155 tons. The steam locomotive used in the night service on Smelter Hill was similar to that used in the day service. When the electric engines were put on the night service all the handling of ore between East Anaconda and the concentrators was done electrically, and the hauling capacity per crew was so much greater that it was no longer necessary to have a "spotter" crew on the night shift so that this crew was eliminated, and the night crew hauling the ore up Smelter Hill did their own spotting on arrival at the concentrator yards, it being no longer necessary to make the regular number of trips. Thus, where formerly during steam operation four engine and train crews had been required, now with electric locomotives three similar crews were able to do the same work and in less time, thereby reducing the number of crews required in this particular service 25 per cent.

On July 9th the stock bin engine was replaced by an electric unit. This engine is engaged mostly in a switching service, placing cars of coke, coal and other supplies at the smelter. The type of steam engine used here was the same as that used for the "spotter" service described above.

Another engine locally known as the "tramp" because of the irregularity of the time or place of its service was partially replaced on July 24th. As some of the tracks over which this engine had to operate at times had not been equipped with overhead wires, the infrequency of their use not warranting the expense when other conditions made it necessary to keep one or more steam locomotives in operation, the service of this

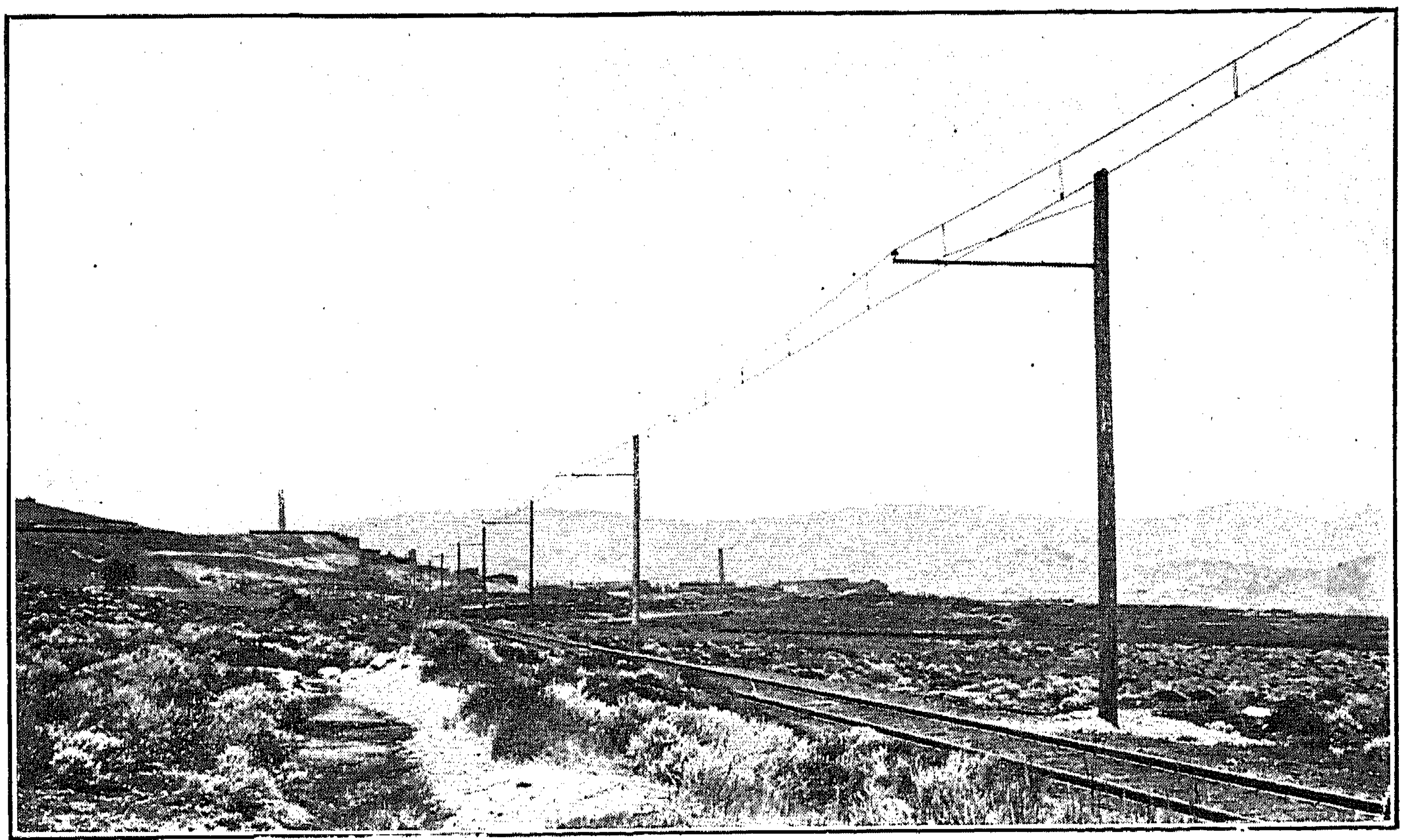


FIG. 13—BRACKET TANGENT CONSTRUCTION ON SMELTER HILL [COX]

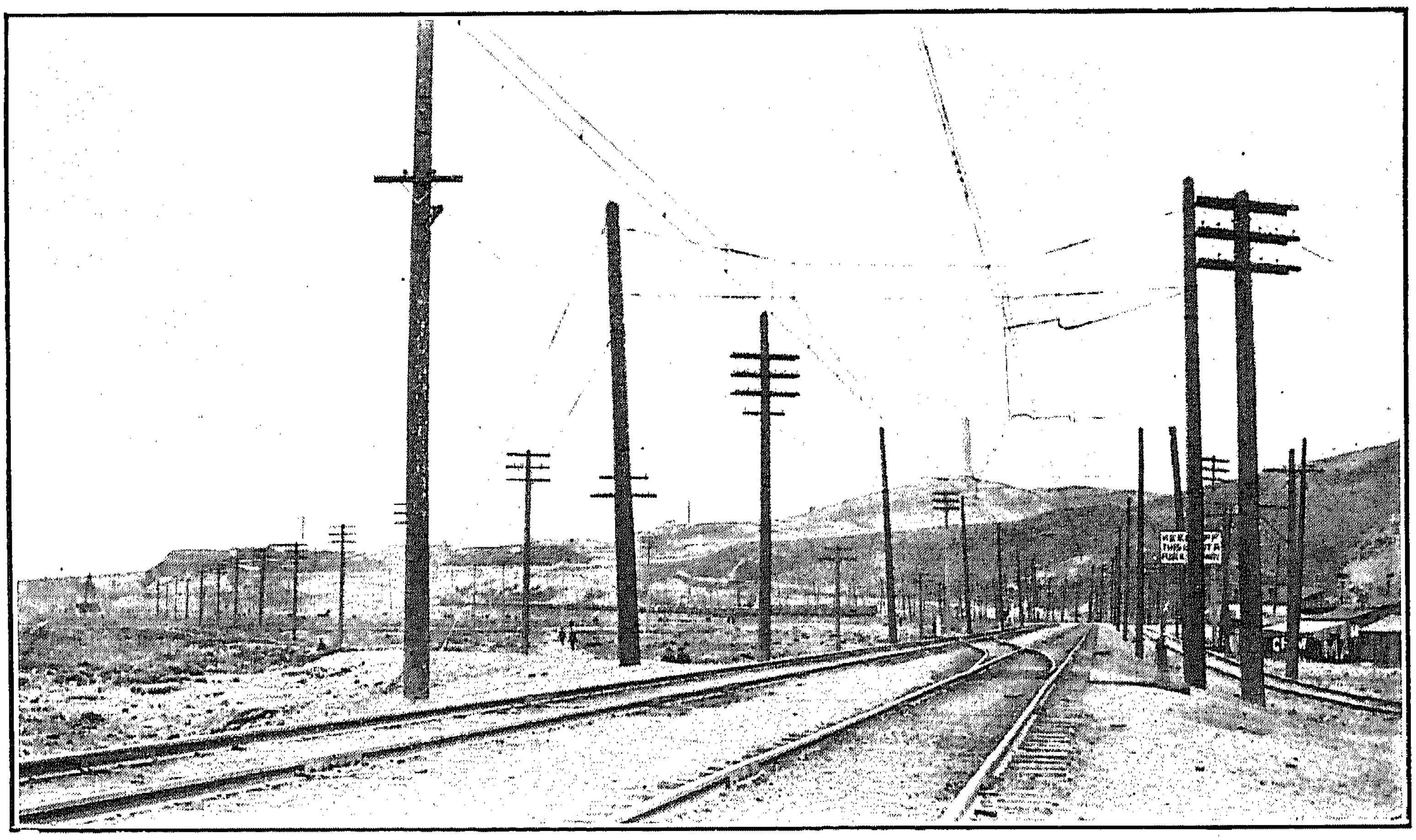


FIG. 14—DOUBLE TRACK SPAN CONSTRUCTION ON MAIN LINE AND GENERAL VIEW OF SMELTER HILL FROM WEST OF EAST ANACONDA YARDS

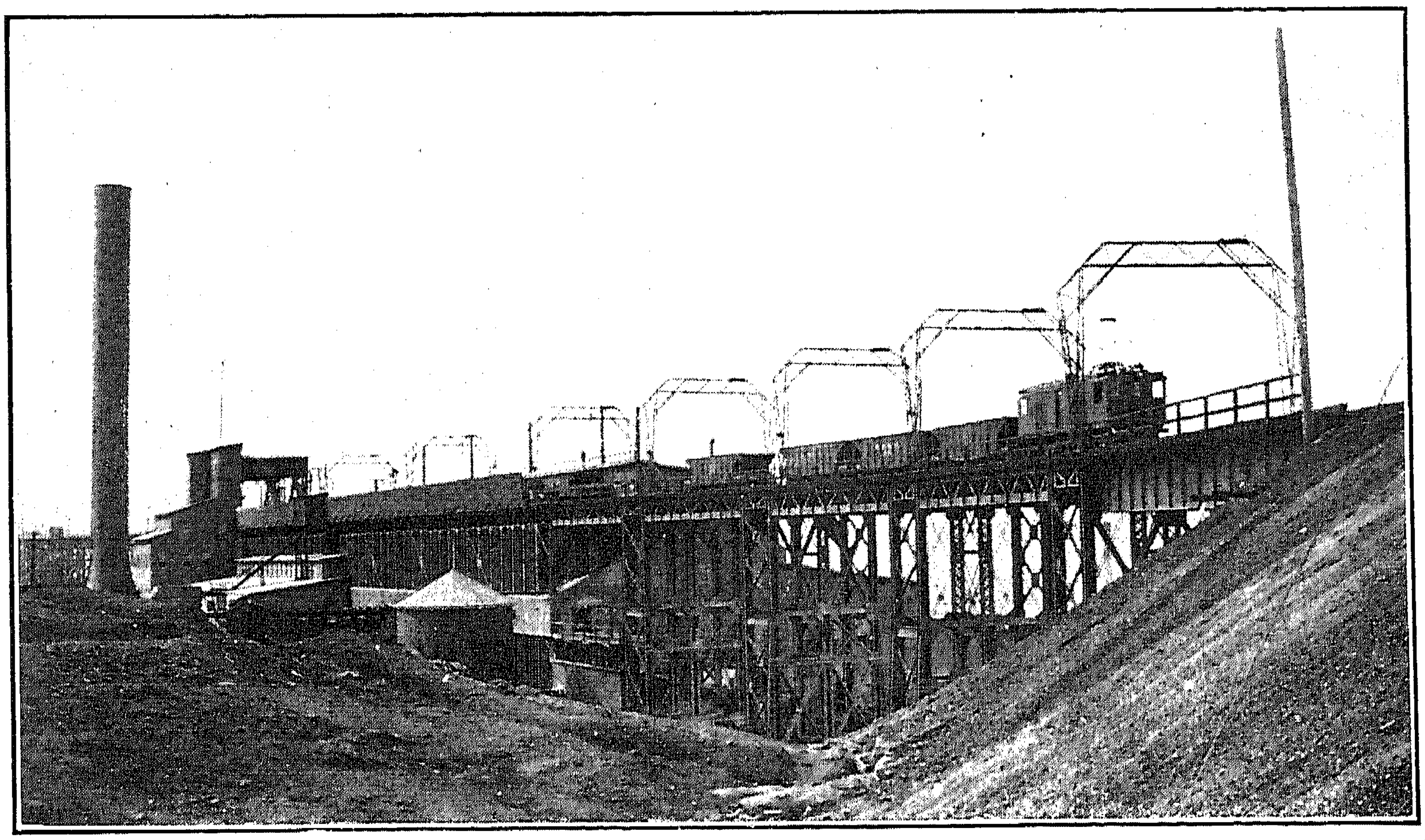


FIG. 15—STORAGE BINS AT CONCENTRATOR [COX]

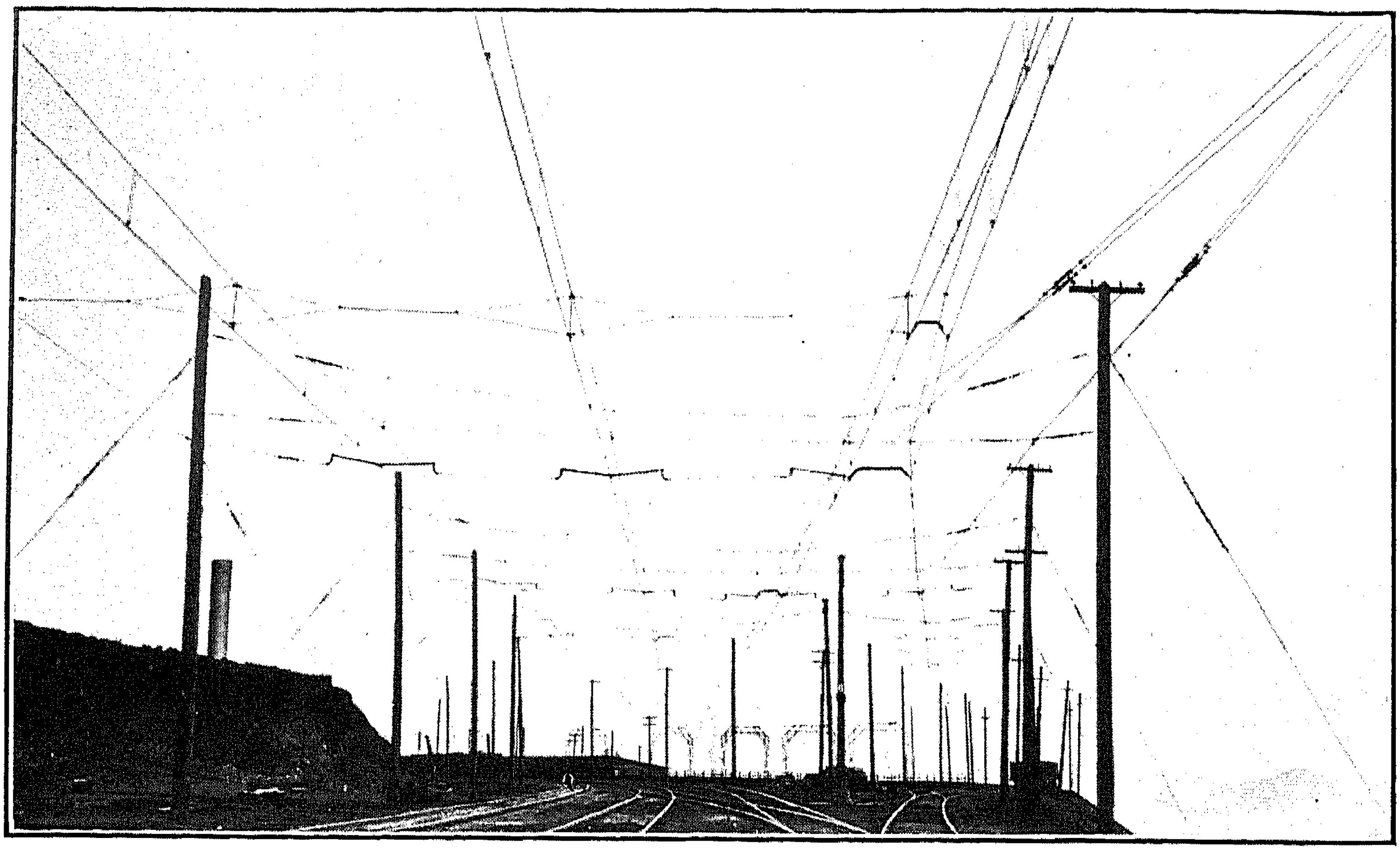


FIG. 16—CONCENTRATOR YARDS [cox]

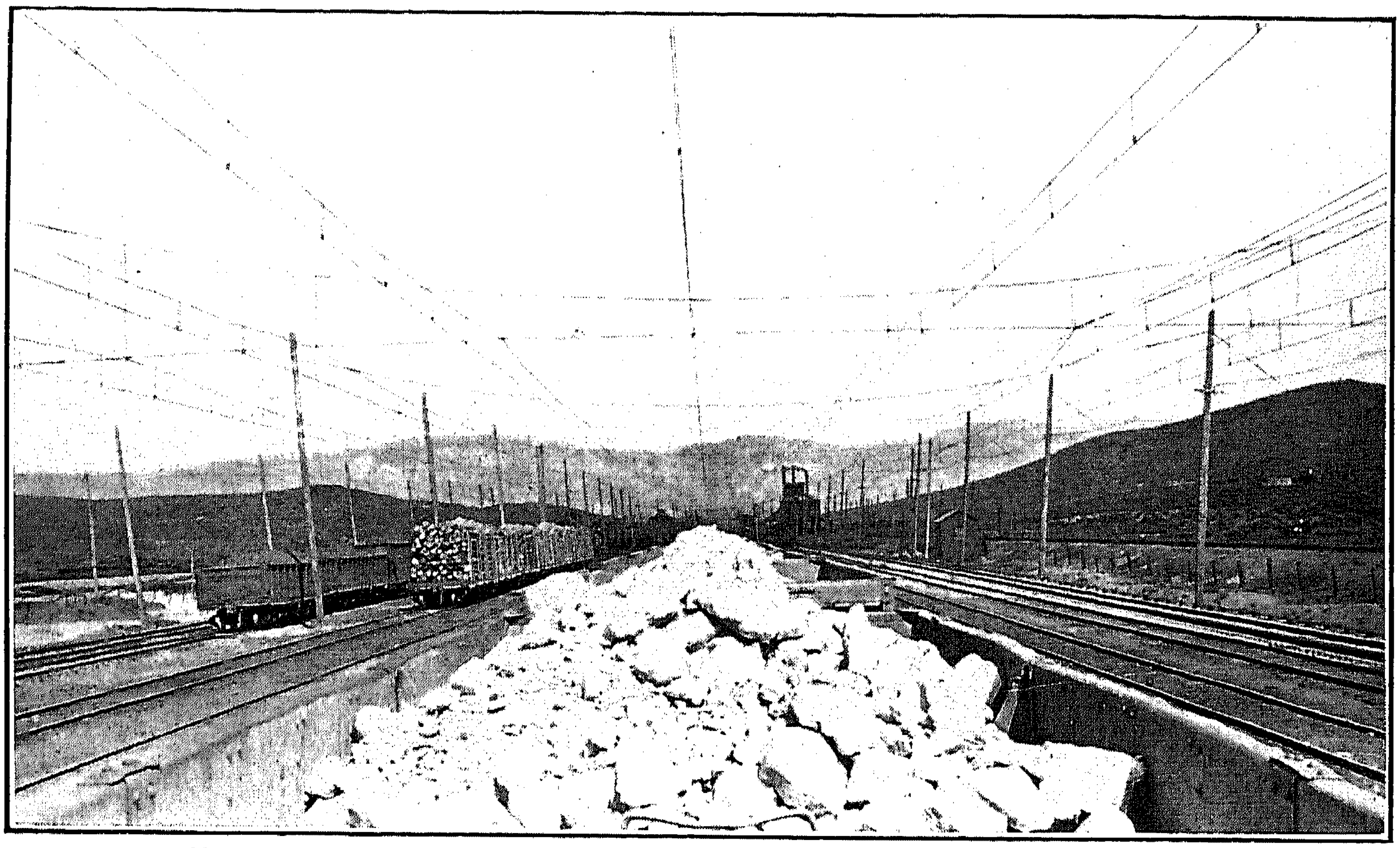


FIG. 17—OVERHEAD CONSTRUCTION IN ROCKER YARDS [cox]

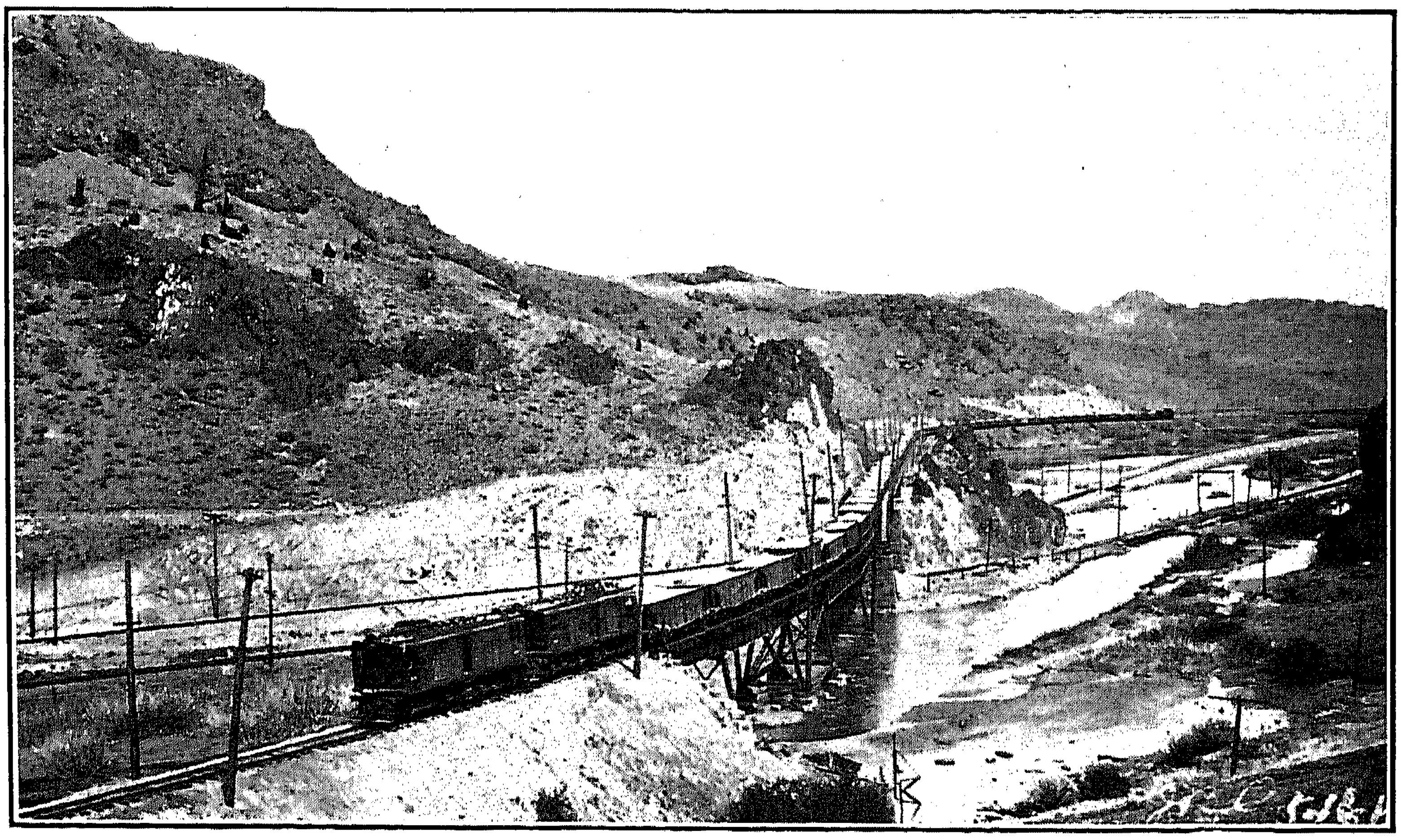


FIG. 18—SIXTY-FIVE CAR ORE TRAIN--TOTAL TRAILING LOAD 4550 TONS [cox]

electric unit was intermittent. This practically completed the electrification of the Smelter Hill service and no further extension of electrical operation was made until October, as the trolley construction on the main line was not completed until that date.

On the forenoon of Sept. 30th an inspection trip was made over the main line from Anaconda to Butte and in the afternoon a special train carrying officials and visitors from a neighboring road was taken from Butte to Anaconda and return by one of the electric locomotives intended for the passenger service. On October 1st the regular passenger service between Butte and Anaconda was taken over for electrical operation. The steam locomotives used in the passenger service weigh approximately 80 tons, 60 tons of which are on drivers, the tender loaded weighing 52 tons, making the total weight of engine and tender 132 tons. The distance between the stations—Anaconda to Butte—is 25.7 miles, the schedule time for the trip, one hour. No change has been made in this time, though a reduction of 20 per cent would be possible with the electric locomotives were such desired. The standard passenger train consists of one mail and baggage coach and two to four passenger coaches, but as many as 12 passenger coaches are handled by a single electric unit on special occasions, such as excursions and on holidays.

The baggage coaches average approximately 40 tons in weight and the passenger coaches 45 tons each making, the gross weight of the three-car electric train approximately 210 tons, whereas that of a similar steam train was 262 tons, showing a reduction of 19 per cent in favor of the electric locomotive with approximately 33 per cent more weight on its drivers. As had been done in the freight service, the steam enginemen in the passenger service were transferred from the steam to the electric locomotives with but little previous instruction, and after the first day or so were left mostly to themselves. It may be of interest to note here that on the day shift, averaging four trips per day, during the first five months the passenger train did not come in late a single time on account of engine trouble. A comparison of the delays to the passenger trains for the month of June, 1913, steam operation, with the same month, electrical operation, 1914, as shown in Table V, results as follows:

	No. of Trains	Delays on Account of				Total Delays
		Meeting Points	Power	Engine Failure	Lost Run Time	All Causes
		Hr. Min.	Hr. Min.	Hr. Min.	Hr. Min.	Hr. Min.
Steam, 1913	272	15 : 49		44	4 : 13	20 : 46
Elec., 1914	280	3 : 54	27	24	25	5 : 10
Decrease	8*	11 : 55	27*	20	3 : 48	15 : 36
Percentage of saving due to electrical operation	2.94*	75.66		45.45	90.10	75.12

* Increase.

June was taken at random for a comparison, as that month's records were still in the office file but the results are considered representative of general performances.

On October 10th a double-unit electric locomotive was put in the day freight service on the main line between East Anaconda and Rocker, a distance of 20.1 miles. The steam locomotive replaced in this instance was of the Mastodon type weighing 103 tons, 77 tons of which was on drivers, the tender loaded weighing 55 tons, making the total weight of locomotive with tender 158 tons. The standard train hauled on the trip west was 50 to 55 loaded ore cars weighing approximately 3500 to 4000 tons gross and the average running time of such trains where no stops were made was about 1½ hours, corresponding to an average speed of approximately 13.4 miles per hour. In the beginning the electric locomotive took only the standard train but made the trip without stop in about one hour, corresponding to an average speed of 20 mi. per hr. The ruling gradient on the westward trip is 0.3 per cent and about half the distance is down grade. On the 0.3 per cent grade with a 55-car train, the steam locomotive made about seven mi. per hr. The electric locomotives with similar train now make about 16 mi. per hr. on the same grade.

The weight of the trains hauled by the electric locomotives on this run has been gradually increased up to 65 loaded ore cars averaging about 71 tons each, making the gross weight ling about 4620 tons. Adding 160 tons for the weight of double-unit electric locomotives and 20 tons for the caboose es a gross train weight of approximately 4800 tons.

he remainder of this main line freight service was gradually en on during the months of October and November, thus pleting the electrification of the main line service. As y as 76 ordinary freight cars loaded with coal, coke and eral merchandise have been taken in a single train on the t-bound trip and 85 empties are frequently taken from t Anaconda to Rocker east-bound, the ruling grade being per cent.

able IV gives comparative results of the month of June 1913 m operation vs. the same month, 1914, electrical operation his main line service, showing that with a slight increase in total tons of ore hauled the average tons per train was in- ased from 1761 to 2378 or 35 per cent, thus decreasing the rage number of trains per day from 12.5 to 9.3, or 25.6 per t.

able III, giving a comparison of the time per trip for se trains, is representative of the gain in this direction to be led to the decrease in the number of trains. The average e per trip during steam operation was approximately two rs and 25 minutes, while with the electric locomotive it was roximately one hour and 45 minutes, showing a decrease 40 minutes, or 27.5 per cent. These figures represent the e put in by the crews between Rocker and Anaconda, the tance being 21.8 miles.

he result of these improvements is indicated in Tables I d II, which show that the overtime in this particular service been decreased 73.5 per cent and the total time 42 per cent, ulting not only in greater economy to the railway company in shorter and easier hours for the crews.

he service on the Missoula Gulch line running between cker and Butte Hill yards was taken over for electrical opera- n on October 20th. This line is 4.5 miles in length and the ing gradient 2.5 per cent, Fig. 5. The steam locomotives d on this line were of the Mastodon type, weight 106 tons, tons of which were on the drivers, the tender loaded weigh- 56 tons, thus making the total weight of engine and tender 2 tons. Two complete crews had been required to handle s service during steam operation, averaging six trips per day h. A single crew with a double-unit electric locomotive has been doing this work successfully. Thirty-five to 45 loaded ore cars are taken down from Butte Hill yard to Rocker, and about an equal number of empties taken up. In addition to the empties, large quantities of timber and supplies for the mines are delivered over this line.

TABLE I

Number of Hours Engine Crews were Employed in Various Services—June 1913 Steam Operation

	Anaconda Yard		Butte Hill Yard		Local		Road	
Date	Regular Time Hr.	Over Time Hr.	Regular Time Hr.	Over Time Hr.	Regular Time Hr.	Over Time Hr.	Regular Time Hr.	Over Time Hr.
June 1	80	14	20	4.50	20	3.25	30	13.75
2	90	6.50	20	6.50	20	5.75	40	17.25
3	50	5	—	—	20	5.25	40	15
4	70	11.75	20	8.25	20	6.75	30	11.50
5	80	11.75	20	8.00	20	6.00	30	12.25
6	70	9.25	20	9.00	20	10.00	30	14.50
7	80	13.75	20	8.75	20	6.50	30	11.25
8	70	8.00	20	8.75	20	4.75	30	12.25
9	70	10.50	20	11.50	20	8.25	30	11.50
10	80	8.75	20	7.75	20	2.00	30	9.00
11	80	13.	20	10.25	20	7.00	30	10.50
12	70	7.00	20	2.00	20	5.25	30	12.00
13	40	5.25			10	1.00	20	6.75
14	70	12.25	20	11.25	20	7.50	30	9.50
15	70	10.25	20	8.75	20	5.25	30	11.00
16	80	8.75	20	9.75	20	16.00	30	9.25
17	80	7.75	20	9.00	30	11.00	30	15.25
18	70	12.25	20	7.50	20	10.75	30	12.50
19	70	9.50	20	9.00	20	3.75	30	8.00
20	80	12.00	30	10.75	20	5.75	30	8.75
21	80	9.75	20	10.25	20	3.50	30	12.75
22	70	5.50	20	7.75	20	5.75	30	10.00
23	70	7.00	20	8.25	20	6.75	30	8.75
24	80	7.50	20	4.50	20	8.00	30	9.00
25	70	9.25	20	6.00	20	9.00	30	11.50
26	80	10.25	20	9.00	20	7.00	30	13.27
27	70	7.75	20	7.50	20	7.00	30	10.25
28	70	5.50	20	2.50	20	4.75	30	9.00
29	80	6.00	20	1.50	20	3.75	30	9.75
30	80	8.75	20		20	7.00	30	9.50
Total	2200	274.50	570	208.50	600	194.25	910	335.50

Tons Ore Hauled During Month—311,450.

On November 25th, the last of the electric locomotive units went into service, thus completing the electrification originally intended. The full electrical service has, therefore, now been in operation more than nine months and that on Smelter Hill more than 15 months, so that the total locomotive-miles operated would be approximately close to an average year's performance.

TABLE II

NUMBER OF HOURS ENGINE CREWS WERE EMPLOYED IN VARIOUS SERVICES—JUNE 1914 ELECTRICAL OPERATION

	Anaconda Yard		Butte Hill Yard		Local		Road	
Date	Regular Time	Over Time	Regular Time	Over Time	Regular Time	Over Time	Regular Time	Over Time
June 1	70	7.25	20	1.25	20	2.50	30	2.25
2	70	8.25	20	4.00	20	2.50	30	5.00
3	70	9.50	10	1.00	20	4.00	30	1.25
4	60	7.25	10	2.00	20	2.75	30	4.25
5	60	12.50	10	2.00	20	2.75	20	2.50
6	60	7.25	10	2.00	20	2.50	20	2.25
7	70	8.25	10	2.00	20	2.00	20	6.25
8	60	8.75	10	1.75	20	2.75	20	3.00
9	60	10.50	10	1.50	20	4.75	20	4.75
10	60	11.25	10	1.75	10	1.00	20	1.75
11	60	5.00	10	1.50	20	3.75	20	1.25
12	60	9.00	10	1.00	20	2.00	20	1.25
13	30	1.75	10	1.00	10	1.00	10	4.00
14	60	5.50	10	1.25	20	2.25	20	1.25
15	60	6.50	10	1.00	20	2.75	20	1.50
16	60	4.00	10	1.50	20	2.50	20	2.00
17	60	7.75	10	1.00	20	3.00	20	2.75
18	60	8.75	10	1.75	20	2.25	20	1.50
19	60	7.25	10	3.00	20	2.25	20	2.25
20	60	10.75	10	1.75	20	2.25	20	5.75
21	60	8.75	10	1.75	20	2.25	20	1.25
22	50	5.50	10	1.00	20	2.75	20	2.25
23	60	6.75	10	1.00	10	1.50	20	3.50
24	60	11.25	10	1.50	20	3.00	20	3.50
25	60	7.75	10	1.50	20	2.25	20	5.25
26	60	5.75	10	1.25	20	2.50	20	1.75
27	60	8.50	10	1.25	20	2.00	20	3.75
28	60	4.25	10	3.00	10	1.75	20	2.00
29	60	6.00	10	1.00	10	1.75	20	5.50
30	60	10.50	10	1.25	20	2.25	20	3.50
Total	1800	232.00	320	48.50	550	73.50	630	89.00
Decrease	400	42.50	250	160.00	50	120.75	280	246.50

	Regular	Over	Total
Total time 1913—Steam..................	4280.00	1012.75	5292.75
" " 1914 Electric..................	3300.00	443.00	3743.00
Decrease..................................	980.00	569.75	1549.75
Percentage of decrease..	22.89%	56.26%	29.28%

Tons ore hauled during month—319,700

This was the first installation of 2400-volt direct-current apparatus for the operation of a railway in this country, 1500 volts being the highest heretofore installed for such a purpose.

The results have been more satisfactory than had been anticipated and the development charges due to such imperfections as usually appear during the first year of operation have been perhaps smaller than is customary with an undertaking of like magnitude, even where standard apparatus is used.

TABLE III

COMPARISON OF TIME REQUIRED PER TRIP OF FREIGHT TRAINS.
BETWEEN ROCKER AND ANACONDA—FIRST 2 DAYS OF JUNE 1913, STEAM OPERATION, WITH CORRESPONDING 3 DAYS ELECTRICAL OPERATION.

1913 Steam					1914 Electric			
East Bound.			West Bound		East Bound		West Bound	
Train No.	Tons	Time	Tons	Time	Tons	Time	Tons	Time
		Hr. Min.		Hr. Min.		Hr. Min.		Hr. Min.
1	255	1 : 13	1705	2 : 00	380	1 : 02	2915	2 : 00
2	1010	1 : 50	2848	2 : 05	314	1 : 15	3092	2 : 00
3	1010	3 : 20	3760	2 : 10	1336	1 : 45	4088	1 : 20
1st 4	915	2 : 40	3420	2 : 30	1260	1 : 40	3830	1 : 10
5	1047	2 : 30	2944	3 : 45	1240	1 : 40	4009	2 : 05
6	1000	2 : 20	2935	2 : 05	..	..	..	..
7	1010	4 : 00	..	..	..	..	..	..
1	415	1 : 07	3110	3 : 40	416	1 : 10	3100	2 : 00
2	1010	2 : 10	3760	2 : 10	1154	1 : 40	3220	1 : 25
2nd 3	1010	2 : 45	2884	2 : 00	1298	2 : 00	3752	2 : 20
4	1010	3 : 00	3420	2 : 00	458	1 : 45	4029	2 : 10
5	1104	2 : 20	3420	2 : 00	1232	2 : 00	3720	2 : 20
6	1000	3 : 00	2910	2 : 50	1190	1 : 55	2840	2 : 35
1	380	1 : 02	3380	2 : 50	470	1 : 03	2515	1 : 15
2	1010	1 : 50	1630	2 : 45	1280	1 : 40	3964	1 : 10
3rd 3	992	2 : 50	200	2 : 00	1298	2 : 05	4098	1 : 30
4	884	2 : 20	0	1 : 20	482	1 : 40	3760	1 : 40
5	1046	2 : 40	3150	2 : 30	1074	2 : 10	3138	2 : 30
6	1084	3 : 15	2770	2 : 40	1200	2 : 15	0	1 : 10
Totals 19	17192	46 : 12	18-48246	43 : 20	17-16082	28 : 45	17-56070	30 : 40
Av'ge per Train.....	905	2 : 26	2680	2 : 24	946	1 : 41	3298	1 : 48

Grand Average. 1768 tons per train, time per trip 2.25; 2150 tons per train, time per trip 1:45.

Result. 20.0% increase in tonnage per train, 27.58% decrease in time per trip.

*On June 5th, 1914, one main line crew was taken off and the tonnage of the remaining trains increased so as to handle the regular business.

Difficulties especially attributable to the higher potential have been negligible, and while there have been occasional instances of arcing and flashing or short circuits due to ordinary causes, the resultant damages have been really smaller than might be expected from a like occurrence on a 600-volt installation of equal capacity.

The original brushes supplied in the motors chipped badly

TABLE IV

COMPARISON OF FREIGHT TRAIN MOVEMENTS BETWEEN ROCKER AND ANACONDA. STEAM OPERATION FOR MONTH OF JUNE 1913 WITH ELECTRICAL OPERATION FOR SAME MONTH 1914

	1913 Steam				1914 Electric			
	East Bound		West Bound		East Bound		West Bound	
Date	No. Trains	Total Tons	No. Trains	Total Tons	No. Trains	Total Tons	No. Trains	Total Tons
1	7	6247	6	17612	5	4530	5	17934
2	6	5549	6	19504	6	5748	6	20661
3	6	5396	6	11130	6	5804	6	17425
4	7	5584	6	14632	6	6127	6	18332
5	7	5848	6	14625	5	5334	5	17155
6	7	5877	6	19471	4	4804	4	17563
7	7	5698	6	21021	5	6579	5	19073
8	7	6388	7	17023	5	6083	5	14170
9	6	5508	7	12507	5	5796	4	15292
10	6	5039	6	19240	5	6027	5	16926
11	6	5381	5	15925	4	5345	4	12832
12	5	4376	6	18112	5	5670	5	17881
13	5	3705	5	9565	2	2322	1	3042
14	6	4912	6	7841	4	4638	4	13803
15	7	5652	7	17691	5	5262	4	15761
16	6	5180	7	17518	4	5116	4	16408
17	6	5475	6	16090	5	6433	5	20581
18	6	5483	6	16592	4	5141	4	17546
19	7	6003	6	18301	5	6661	5	18489
20	7	5277	6	22283	5	6768	5	17992
21	7	5737	6	18986	4	5120	4	11932
22	7	5082	6	15464	5	6017	5	15613
23	6	5386	6	11941	4	4121	4	15930
24	6	5098	6	18210	5	6556	5	18917
25	7	5544	7	17992	5	6531	5	16855
26	7	5690	6	18304	5	6782	5	18593
27	7	5935	6	14764	4	4362	4	18038
28	7	5754	5	17297	4	5047	4	14884
29	6	5105	6	19899	5	6455	5	17941
30	6	5221	6	17584	5	6617	5	18128
Total.......	193	163,130	182	497,124	141	167,796	138	495,697
Average....	6.4	845	6.1	2,731	4.7	1,190	4.6	3,592

Grand Average 12.5 trains per day, 1761 tons per train. 9.3 trains per day, 2378 tons per train.

Results—25.6% less trains. 35.0% greater tonnage per train.

and before all these had been replaced it was often found when the units were brought in for regular inspection that some of the brushes were broken entirely into pieces, and while there was evidence that a flash-over might have occurred at some time, no harm had resulted other than the blowing of the motor fuse, on the replacement of which the engine was continued in service until its regular time for inspection, when the cause of the fuse blowing would first be discovered.

The fact that the locomotives continued in service thus is sufficient evidence of the harmlessness of the arc-over and in no instance of the kind has any real damage been done. The locomotives have made from 25,000 to 50,000 miles each and without exception the motors are in excellent condition. The wear on the commutators is imperceptible and the general performance of the entire equipment is quite as satisfactory and promising as that of any railway equipment with which we have had experience in similar service.

The overhead construction has been quite satisfactory and a recent examination of the trolley wire shows no indication of unusual wear. The roller pantographs are operating quite successfully, the average life of these being from 10,000 to 12,000 miles per roller. Where a double-unit locomotive is operated, the two pantographs are connected electrically by a main bus line, and the average current collected by each, when ascending the grades with standard loads, is from 350 to 400 amperes. Two pantographs operating in multiple thus will collect more than double the current that can be successfully collected by a single pantograph for the reason that sparking is usually due to the momentary breaking of contact between the trolley wire and the roller caused by hard spots in the line. When two pantographs are operated in multiple both do not encounter these hard spots at the same instant, hence one of the two is more apt always to be making good contact, so that the flow of current is not so frequently interrupted and consequently the sparking is greatly reduced. The double units operating on Smelter Hill were run experimentally for several days with only a single roller making contact with the wire, the operation being quite successful with the single roller collecting an average of 650 to 750 amperes while running at 16 to 17 mi. per hr. and 800 to 1000 amperes during the accelerating period in multiple. The sparking was not serious except at hard points in the line, and with two rollers in multiple there should be no difficulty in collecting 500 to 600 amperes per roller, which at 2400 volts should be equal to the requirements of any ordinary locomotive unit.

The bearings first used in the rollers were provided with ordinary bushings lubricated with oil but when the bushings became slightly worn the oil was thrown out along the spindle and had to be replenished at comparatively frequent intervals. This was not serious in the operation of the freight locomotives but became more so when the passenger service was started, as the higher speed caused the oil to be thrown out more quickly, resulting in very short life of the bushings. Slight changes were made in the bearings and grease was substituted for the oil as a lubricant, which proved quite satisfactory. However, the vibration which results from too much play in the bearings of the roller when operating at high speeds made it desirable to increase the life of these bearings as much as possible, so that, later, roller bearings with grease lubrication were installed with excellent results. As yet, these have not been in operation a sufficient length of time to indicate definitely how long they may be expected to last, but it would appear that the bearing will last much longer than the roller and that the attention required for the adjustment and lubrication of the bearing or the roller will be negligible.

On account of a decision of the mining company to divert to the Washoe smelter, at Anaconda, the shipment of approximately 3000 tons of ore per day that had previously been sent to the smelter at Great Falls, which will increase the ore traffic over the Butte, Anaconda & Pacific approximately 25 per cent, an extra motor-generator set, a duplicate of the original sets, has been installed in the Anaconda substation as a spare set, and four additional electric locomotive units were ordered and will be delivered within the next three months. These units will be duplicates of the original ones except that they are to be arranged for operating with an extra tractor truck attached when desired. This tractor truck will be a duplicate of the standard truck used under the regular units, with two standard motors mounted upon it with the necessary arrangements for coupling, both mechanically and electrically, so that the standard unit and the tractor truck may be operated as a single unit. The motors of the tractor truck are connected with those on the standard unit in such a manner as to place all six motors in series on the series points of the controller, and with a series-multiple connection with three motors in each series, on the multiple position of the controller. This arrangement will make the tractive effort of the new unit 50 per cent greater than that of a standard unit for the same input, with a reduction in the free running speed of about 33⅓ per cent.

This arrangement was made advisable because of the increase in the weight of the trains taken up Smelter Hill, amounting to approximately 56 per cent. A single unit when used in the "spotting" service is taxed close to the slipping point of its wheels when accelerating these heavier trains on the 0.5 per cent grades under ordinary conditions of weather, and has to be handled very carefully with the continuous use of sand when the condition of the rails is unfavorable. Connecting the additional motors in series will also result in considerable power economy, since with a single unit the controller is seldom off the series resistance points, on account of the heavy trains handled and the short movements required.

Small change in the personnel of the maintenance or operating departments of the railway has been made on account of the electrification, nor has there been any reduction in salaries or wages. An extra man with electrical experience was placed in the shops to supervise the electrical repairs to the locomotives and three linemen were retained for the maintenance of the trolley system.

The three steam switching locomotives used for concentrating the ore at and distributing supplies from Butte Hill yards are continued in this work for reasons heretofore stated. Another steam locomotive is used on the Georgetown branch and a fifth one operates at intervals over unelectrified tracks at the Anaconda end. Approximately 20 per cent of the total locomotive-miles now being operated is by these five steam locomotives, the cost of which, as shown in Table VI, is upwards of 40 per cent of the total cost of all locomotive performance.

The electrification of the remaining tracks on Butte Hill has been recommended and no doubt will be commenced at an early date. Table VI referred to was made up from the regular monthly locomotive performance sheets of the railway company, from which the principal saving resulting from the electrification may be noted. The saving from the partial substitution of electric power for coal is the chief item, being at the rate of $150,727.04 per year, which is remarkable when it is considered that more than 39 per cent of the total combined costs for fuel and power for the period considered was for coal and charged against electrical operation. In this instance the saving on this item alone would undoubtedly justify the

1914	10	30				30	10	10 : 30		30	45			11 : 45	12 : 15

expenditure covering the entire cost of electrification. It is to be noted that with a single exception, that for depreciation of equipment, every item of expenditure in the locomotive performance sheet shows a substantial percentage of decrease in favor of electrical operation.

It is the practise of the railway company to adjust depreciation charges on all locomotives at the beginning of each half year. The amount to be charged to the depreciation of a new locomotive for the first half year it is in service is determined by taking a fixed percentage of its cost to the company, one-sixth of this amount being charged against the locomotive each month for the half year, at the end of which the amount of the depreciation for the period is deducted from the original cost of the locomotive to give a new value, of which the original fixed rate of percentage is taken in determining the amount of the depreciation for the following half year, and so on.

The Interstate Commerce Commission ruling does not permit a depreciation charge until the locomotive actually becomes the property of the railway company and as the electric locomotives were not formally taken over by the company until March, 1914, the proper monthly charge begins only with that month in the regular monthly performance sheet from which Table VI was compiled. In fairness to the performance sheet, only the proper monthly depreciation charges were made, but as some of the locomotives had been in service eight months before these charges began, an adjustment was necessary to make a proper distribution of the back depreciation, so that while Table VI shows only the proper monthly charge for the six months compared, amounting to $8,471.84, in Table VII under "maintenance of equipment" the total back charges were included, amounting to $20,047.48. It is evident that the depreciation reckoned on this basis for the first months of service would be comparatively high.

The total saving from locomotive performance alone as indicated by Table VI is at the rate of $237,581.82 per year, to which should be added the credit of handling an increase of traffic at the rate of 13,938,136 ton-miles per year or 8.77 per cent more than was handled by the steam locomotives during the period compared. To this saving from locomotive performance should be added the saving from trainmen's wages, which is at the rate of $31,146.30 per year, or a decrease of approximately 21 per cent, due largely to the elimination of overtime (Tables I and II), making the total saving from these two items $268,728.12 per year. From this should be deducted $10,839.12 for maintenance of the distribution system, leaving $257,889 as the net operating saving per year due to electrical operation.

The roadmaster states that it is quite evident that the electric locomotives are much easier on the track at curves but that there is no noticeable difference on tangent track, and that while sufficient time has not yet elapsed to form definite conclusions, present indications lead him to expect that any difference relative to his work will be favorable to the electric locomotives.

Arranging the items of expense appearing in Table VI in the order of usual appearance in the summary of a standard locomotive performance sheet, and placing them on a yearly basis, results as follows:

Item of Operating Expenses	Steam 1913	Electric 1914	Decrease 1914	Per cent decrease
Fuel and power	$315,235.74	164,508.70	150,727.04	47.81
Repairs	124,787.90	92,278.08	32,509.82	26.05
Enginemen's wages	104,461.18	71,225.88	33,335.30	31.81
Enginehouse exp.	29,907.80	18,638.38	11,269.42	37.68
Water	4,953.66	1,193.70	3,759.96	75.90
Lubricants	9,751.44	4,942.32	4,809.12	49.30
Other supplies	5,823.52	4,552.36	1,271.16	21.83
TOTAL LOCOMOTIVE PERFORMANCE	$594,921.24	$357,339.42	237,581.82	39.93
Trainmen's wages	147,632.30	116,486.00	31,146.30	21.10
GRAND TOTAL	742,553.54	473,825.42	268,728.12	36.19
Ton-miles hauled	158,917,720	172,855,856	13,938,136*	8.77*

*Increase

The total cost of the electrification, including a change of signal system on Smelter Hill, the extra motor-generator set recently installed at Anaconda, interest during construction and all incidentals due in any way to the electrification, was in round numbers $1,201,000. This does not include the step-down transformers, which are the property of the power company, but on the other hand no deduction has been made for the salvage due to the elimination of 20 steam locomotives.

If a correction be made for the item of depreciation in Table VI, charging the regular monthly amount of $2711.13 begun in March for each of the six months, making the total of this item for the period $16,266.78 instead of $8,471.84 as it stands on the performance sheets, the total saving per year from locomotive performance would be reduced to $221,991.94, making the total net saving $242,299.12, which is equivalent to 20.02 per cent on the entire cost of the electrification, to say nothing of the increased capacity of the lines, the improvement in the service and more regular working hours for the crews, as is indicated in Table V, comparing the delays to traffic, and Tables I and II, showing the decrease in overtime.

From Table VII it will be seen that if taken on the basis of the increase shown in net operating revenue, or operating income, this percentage is slightly greater, the rate of increase per year for these items being $288,150.80 and $282,016.96, respectively.

The estimate on which the decision to proceed with the electrification of the road was made, placed the annual net saving expected at 17.5 per cent of the cost, so that the results financially have been quite as satisfactory as the general performance of the equipment.

DISCUSSION ON "ELECTRIFICATION OF THE BUTTE, ANACONDA AND PACIFIC RAILWAY" (COX), SPOKANE, WASH., SEPTEMBER 10, 1914.

Paul Lebenbaum: This paper looms up as an oasis of facts in a desert of glittering generalities, and records a distinct step forward and upward in heavy railway electrification. It is unique in that it sets forth, not only facts, but actual figures on operating results, for a road that made the change from steam to electricity solely in order to obtain increased capacity and greater economy in operation. Most, if not all, of the heavy electrification has been done for the purpose of overcoming an operating condition for which steam was unsuited, such as the New York terminal electrifications, the work of the Great Northern at the Cascade Tunnel, etc. It must therefore be peculiarly gratifying to the management and its engineers that the economies resulting from the change were so quickly and positively established.

It would, no doubt, take some time to properly correlate and digest the many figures that Mr. Cox has presented; what little I have to contribute to the discussion will therefore be in the nature of a comparison with some of the results obtained on the Portland, Eugene & Eastern Railway, operating at 1500 volts over some 105 miles of single-track road, exclusive of sidings. All passenger movements are electric, freight being still handled by steam, the speeds in passenger service exceeding 50 miles per hour.

It appears that 90 per cent of the B. A. & P. train mileage is made in freight service at the comparatively low speed of 16 to 17 miles per hour, while all of our passenger service is at much higher speeds. Both roads use the US-122-E. type of pantograph, having a five-inch diameter roller, as a current collector, the B. A. & P.'s problem being to pick up large currents at low speeds and the P. E. & E.'s smaller currents at high speeds.

We make approximately 45,000 train miles, or 120,000 motor car miles, per month. Each motor car uses its pantograph, there being no power bus on our equipments. I was therefore interested in Mr. Cox's statement as to the average life of collectors being 10,000 to 12,000 miles. We have also found it necessary to equip our collectors with a roller type of bearing, discarding the graphite bushings originally furnished. Since that time we have made well over 20,000 miles each on enough collectors to convince us that 50,000 miles should be the average collector life under our conditions, where each motor car takes from 100 to 150 amperes. It no doubt is reasonable to assume that the smaller mileage made by the B. A. & P. rollers is in part due to the heavier currents they must collect; although the lower speeds made by 90 per cent of their rollers should, to my mind, somewhat offset this latter condition.

The whole subject of current collection, in small or large quantities at high or low speeds respectively, presents a very resting problem, the solution for which, at least in this ntry, is yet to be found.

I noted that equipment trouble on the 2400-volt locomotives s negligible. We have also had practical freedom from ous troubles; in one or two instances arcs from the circuit akers have jumped to ground, due entirely to the method nting the gases engendered by the breaking of the current. k Mr. Cox whether the B. A. & P. has had any similar experiences in the breaking of high-voltage arcs.

C. P. Kahler: I note that a comparison has been made tween the electric and steam operation costs of the Butte, conda & Pacific Railroad, and that a 20 per cent earning he investment for electrification is shown, based on the first onths' records of the operating expenses. I would hardly nk that a comparison based on six months' records would e a correct idea of the relative costs of electric and steam eration of this railroad. For instance, take the item of omotive repair costs, which are usually divided into two rts, light running repairs and shop or heavy repairs. Six nths' service with electric locomotives would give very little, nything, on the shop or heavy locomotive repairs, and quently I would judge that the electric locomotive repair ense for the first six months would necessarily be considery less than will be the case after the locomotives have been peration several years and sent through the shops once or ice. I have noticed that the repair costs of steam locomoes usually start out at a very low figure per locomotive-mile, d gradually increase, as the locomotive gets older, until the per locomotive-mile will quite often reach several times e cost when the locomotive first began operating. Consently I would hardly think it proper or fair to the steam omotive operation to compare the first six months' expenses the new electric locomotive operation against the cost of intaining a few old steam locomotives.

The steam locomotives used in operating the Butte, Anaconda & Pacific were not very large when compared with the e of the steam locomotives used on many other railroads, d it would be interesting to know what saving would have en made by replacing the old steam locomotives of the B. A. & P. with new and larger steam locomotives, and also what uld be the saving by electric operation as compared with am operation, using large steam locomotives.

For some time past I have been of the opinion that the eatest saving which would result from electric operation of am railroads would be from the reduction in the steam train rvice, and the data given in Mr. Cox's paper tend to confirm is opinion, for by electric operation three crews are now hauling the same tonnage as four crews did with steam locomotives, duction of about 25 per cent in the train service. As the in crew expense on most roads is usually somewhat near

20 per cent of the total operating cost of the railroad, a reduction of 25 per cent in this expense by electric operation would mean that the total expense of steam operation would be reduced about 5 per cent on account of the reduction in train service alone. Additional saving would, of course, be made on account of the lower cost of locomotive repairs, less engine house expense, and other detailed costs which would result by electric operation.

I note that electric locomotives with four axles, having a combined weight of 80 tons, are used on the B. A. & P. R. R., and that two of these four-axle units are rated as one locomotive of 160 tons. I judge that units of this weight were selected in order to allow one pantograph per unit for collecting current. However, it would appear to me better, in determining the weight of an electric locomotive, to work from the other end. In other words, to determine the maximum weight which your track would support, and make the axle loads of the electric locomotive correspond to this. For instance, the Union Pacific system allows a maximum weight on locomotive drivers of 55,000 pounds, which would make a four-unit locomotive, similar to the B. A. & P. electric locomotives, weigh 110 tons on the drivers, a fairly large size locomotive. The Pennsylvania, I believe, allows as high as 65,000 pounds on each driver, which would make the total weight of a four-driving-axle locomotive equal to 130 tons on the drivers. This would be nearer my idea of a locomotive which would be best fitted for the freight service. This would also make the use of the tractor auxilary referred to, unnecessary.

In conclusion, I would say that while I do not consider the results as absolutely conclusive, the paper is very valuable in that it bears out many claims made as to the advantages and lower economy which would result from electrically operating steam railroads. Further, the fact that the B. A. & P. R. R. is simply a short line would not be an especially favorable condition for expenditures in electric traction work, and the favorable showing which is evidenced by the data given in Mr. Cox's paper would probably be very much better if applied to an engine district of about 150 miles in length, and under such conditions I believe that the earnings which would be made on the investment for electrification work would in many cases exceed the 20 per cent which Mr. Cox claims as the earnings on the investment from the electric traction work of the Butte, Anaconda & Pacific Railroad.

J. C. Ralston: The author designates the engineman, the man who drives the locomotive, as a locomotive engineer, and again he speaks of him specifically as an engineer, I think. Now, 90 per cent of engineers are responsible for an incorrect use of that word. I feel this: that if the four premier engineering societies, namely, the electrical, civil, mechanical, and mining, would all take up this question and use the proper word, we would not be confused as we are by reading in the papers of the hoisting engineers' society and the various societies in domestic lines. I hope that the engineers themselves will follow the correct terminology and then the public will later follow our lead.

A. A. Miller: I ask Mr. Cox to give us a little more description of those tractors; do they have cabs?

W. K. Stacy: I wish to inquire regarding the life of the trolley wire when using the roller collector. I have had experience with the sliding collector and under certain conditions the wear on the trolley wire was excessive. This was particularly apparent with rigid hangers at the ends of line circuit breakers. What style of trolley wire suspension is used on the B., A. & P?

Paul Lebenbaum: After the line had been in operation for about five months, the trolley wire was carefully calipered to determine whether there had been any wear, especially at what might be called hard spots in the line. No measurement taken showed a variation from the true diameter of the wire greater than the 2 per cent variation allowed the manufacturer under our specifications.

J. B. Cox: Referring to the remarks relative to the steel rollers used for the collection of current on the pantographs, these collect 600 amperes at from 16 to 20 mi. per hr. quite satisfactorily. It would be rather difficult to compare the life of the rollers used on the Butte, Anaconda & Pacific locomotives with similar rollers on ordinary interurban cars where they are required to collect a much smaller current and at somewhat higher speeds. The heavier currents required in the operation of the locomotives would undoubtedly account for the much shorter life in this case. The 10,000 to 12,000 miles being obtained from the rollers on the locomotives is equally as great as was expected of them when it was decided to install this type of collector.

As compared with the slider type of collector, the roller is considerably heavier and somewhat more complicated, but on account of its longer life and less wear on the trolley wire in the heavier class of service it has been considered more desirable for the collection of heavy currents. It is generally admitted that the slider is more simple and if it can be perfected so as to collect an equal amount of current with even half the life in mileage obtained from the roller and with equal wear on the trolley it will usually be preferable and would no doubt prove more economical both as regards first cost and maintenance. Considerable progress is being made in the development of a sliding pantograph in the above respects and I am of the opinion that their use will become more general. I have recently seen up to 3000 amperes collected without sparking by a single pantograph with a double sliding collector. This was on the occasion of test running, which gave most promising indications of practical success, but actual service under general operating conditions will be necessary to perfect these sliders in every detail. Personally, I have no doubt but that either type of collector can be made to operate quite successfully under almost any practical conditions.

As to the number of linemen employed in the maintenance of the distributing system, I have given the exact number regularly retained on the pay rolls of the company. The amount stated as being the cost of maintenance of the distributing system was based on the rate of the monthly charges for the six months for which the operating costs are given and cover all items chargeable to this account, which are principally for material, labor and work-train service. These costs are at the rate of approximately $125.00 per mile per year and are about what is expected to be the average cost for at least the normal life of the wooden poles, which is expected to average in this locality from twelve to fifteen years.

In reference to the wear on the trolley wire, this is so small to date that any statement as to actual measurements would be of small value, since the allowable variation in the diameter of the new wire might easily make such figures misleading unless careful measurements had been made and recorded before the electrical service was started. This wear will usually be noticeable first at hard spots in the line where there are pull-offs or rigid hangers. The construction of this line was designed with a special view to flexibility, so as to facilitate the operation of the roller collector as well as to reduce the wear on the trolley, and undoubtedly it is the most flexible construction of the kind in this country at the present time.

Relative to the suggestion that the first six months of electrical operation is too short a time on which to base definite comparisons, I have not stated that such is to be done, but I have given actual figures from official records accompanied by an explanation of the principal conditions under which the results were obtained.

The last six months' full steam operation has been compared with the first six months' full electrical operation and it just so happens that the changing-over period lasted six months, making the comparison for the same months of consecutive years. The systems of accounts were kept identical so that results would be directly comparable; the same men have taken care of the maintenance and done the operating in each case and very much in the regular way, making only such changes as were naturally suggested from the use of the new motive power, and the entire change has been made so gradually that I doubt very much if there has heretofore been such favorable opportunity for obtaining operating costs where so direct a comparison between steam and electric locomotives could be made.

In the first place the conditions for segregating the costs have seldom been so favorable, and secondly, operating companies that would give out such full information have been exceptional.

Precisely the same conditions might not be met on another road, hence exactly similar results would not be expected. The extent of the usefulness of these figures in forecasting results of proposed electrifications depends upon our ability to properly adjust them to apply to any other particular case. It has been suggested that the cost of repairs to the electric locomotive for the period considered is less than it will be in the future and that for this reason the comparison of these items might not be representative, it being unfair to compare the cost of repairs of new electric locomotives with that of steam locomotives which have been in service a number of years. While this is not an unnatural inference, in practise I have not usually found it to be true and in this particular instance I feel confident that the cost of maintenance of the electric locomotives given in Table VI, which includes the charge for depreciation, will be less in the future than it has averaged for the six months in question. The reasons on which this expectation is based are, first: that of the total cost per locomotive mile, amounting to 7.47 cents, 2.46 cents is for depreciation, leaving 5.01 cents as the cost per mile for actual repairs as the term is generally applied. This is fairly high under ordinary conditions but not unreasonably so here under the special circumstances, as it included the cost of considerable experimenting with pantograph rollers and minor improvements to the equipment in adapting them to the special conditions required by the service; so that on the whole about as much work has been done on the locomotives during these six months as will be averaged at any time in the future and the decrease in the rate of depreciation on the basis that it is being determined will more than take care of any probable increase in actual repairs.

Secondly, the old steam organization was retained as far as required for the maintenance of the electrical equipment. It would be unreasonable to expect that they will not improve in efficiency as they become more familiar with the new equipments, and the shop facilities will be gradually improved also, resulting in reducing the cost of repairs on the electric locomotives.

Taking all these circumstances, with which I am familiar, into consideration, I shall be very much disappointed if the cost of maintenance of the electric locomotives per mile operated does not show a gradual decrease during the next few years. I have had considerable experience in connection with the initial operation of electric locomotives and their maintenance during the first two or three years in service, and this experience has led me to the conclusion that the cost of maintenance of an entirely new type of equipment in the hands of an old steam organization will usually be equally as high the first year as the average cost for a number of years after. This is particularly the case where dual equipment is operated and where the costs of minor developments and adaptations are taken care of and charged to the maintenance department. When utilizing the old organization under such conditions, it is a mistake not to begin a regular system of general inspection and repairs at the very beginning so as to get the men as familar with the new apparatus as possible, so that when these repairs are actually necessary they will not only have a definite idea of the work ahead of them but will also be provided with the necessary tools so that they can do the work with the same efficiency as in the case of the steam locomotives. On the whole I have found it more easy to break in old steam organizations to operate and take care of electric locomotives than to adapt electrical men to the work who had not had previous steam railway experience.

It might be of interest to state here that at the end of a year's service a general shop inspection and overhaul of the electrical locomotive was begun with this object in view. The trucks were taken out from under the cab, the motors taken off, the armatures taken out and every thing gone over as thoroughly as possible, including the turning of tires and rebabbitting of armature bearings.

This was done corresponding to similar annual general overhaul of a steam locomotive. The electric locomotive was in the shop one week, whereas four weeks were required on an average for the steam locomotives for a similar overhaul, and the costs in each case were about proportional to the time the locomotives were in the shops; that is, the electric locomotive cost was about one-quarter that of its steam predecessor. The tires on the drivers of the electric locomotive will average somewhat more than double the mileage between turnings obtained from those under the steam locomotive.

The many sharp curves on the entire system result in rapid wear of the flanges.

While I have had little actual experience in connection with the maintenance of new steam locomotives, I have often had occasion to investigate the costs of repairs to steam locomotives. My impression is that on the first installation of a new type of steam locomotive on any road the adaptation and development charges during the first year are apt to make up for the smaller number of general repairs that are required during the first year, much the same as in the case of the electric locomotives. As an instance I will cite the case of a number of large Mallet engines, the cost of repairs for which was 20.46 cents per mile for the first six months, whereas the average cost during the first four years of their service was 23.34 cents. The cost for the second year was greatest while that for the third year was least. I do not believe this is exceptional. In the case of electric locomotives I have in mind a record in which the cost of repairs the first year was 6.7 cents per locomotive mile and for the fifth year 4.1 cent, the average for the five years being 4.85 cents; and another where the cost for the first six months was 5.45 cents per mile and the average cost for the fourth year was 4.98 cents. Both these instances were steam road electrifications with new 600-volt equipment. As a matter of fact most of the records I have seen are of a similar nature, and it is these facts coupled with actual experience that are responsible for my opinion on the subject.

It would be only natural to expect that the cost of maintenance on steam locomotives, during the last six months they were expected to be used, before being replaced by electric locomotives, would be somewhat neglected, and hence the costs per locomotive mile would be less than the average. However, I investigated the records over a considerable period of steam operation and found no very great variation on account of this, but that the figures for the six months quoted were fairly representative.

In this connection it may be stated that the Butte, Anaconda & Pacific Railway has always kept its locomotives in an unusually good state of repair and that the prices paid for all classes of labor are perhaps higher than is paid anywhere else in this country. The fact that the cost of labor is high is not altogether favorable to the electrification, inasmuch as it greatly increased the first cost, but insofar as the operation of transportation and maintenance of locomotives is concerned, it is more favorable, since the number of employees is generally reduced to some extent and the overtime is apt to be considerably less.

Referring to the suggestion that the electric locomotive units should have been larger, this subject was very carefully considered before the design of the locomotive was begun and after an investigation of all the conditions and the general requirements of the work it was agreed that a unit approximating 80 tons on the drivers would give best general results and that no advantage offered by a heavier unit for any part of the service would offset the disadvantages of a mixed type of equipment. Electric units weighing 100 tons are quite common, and the three-phase electric units which have now been in operation on the Great Northern Railway for five years weigh 115 tons each, all of which is on four axles, so that ordinarily there should be no difficulty in providing as heavy a unit as conditions might require. In the case of a mountain division on a transcontinental line it is usually desirable to use as heavy units as the draft gear of the rolling stock will permit. In the case of the B., A. & P. Railway the conditions were not considered generally favorable for the use of larger units. Longer trains than could be handled by a double 80-ton unit locomotive would have required the lengthening of yards, sidings and passing tracks. Heavier units in this case would also have increased the peak loads on the substations and lowered the load factor. The draft gear on the ore cars and many other local conditions had to be considered in this connection, the general result of which led to the adoption of the present unit.

Referring to the burning out of contactors, due to dust or irregularity in following the proper sequence of operation, there have been no instances of serious trouble with contactors, from any causes, so far as I am aware. There have been instances of flashing over of insulators at the back of the contactors, which was thought to have been due to the accumulation of dust from the ore, which contains some copper. There is, naturally, a great deal of such dust, and the blowers located in the cabs of the locomotive cause more of it to be drawn over the apparatus than would be done otherwise. We had really expected much more trouble from this source than actually occurred. These arc-overs did not result in any serious damage. It was only on inspection that it was found the insulators had arced over, as apparently the arcing had occurred when the contactors were opening the circuit so that the current was shut off before the arc did any thing more than burn off the dust, after which there was no further bother.

In one or two instances where the main trolley contactors were involved, the main fuse was blown, but as far as I am aware no contactors have been damaged so as to cause any delay or to require immediate attention. In this particular control equipment the transition between series and parallel connections, where troubles from improper sequence of coming in and out of contactors are most likely to occur, the contactors involved in the transfer are operated by means of a cam which insures a proper and uniform sequence and no troubles whatever have been experienced from this source.

During the first ten months of operation no contact tips had been changed on any of the contactors nor had any repairs to same been necessary. On the whole the contactors on the locomotives show less signs of arcing or burning than on an ordinary 600-volt locomotive in a similar service.

The commutators of the main motors are in such splendid condition that during the visit of some German engineers to inspect the electrification about six months after the locomotives had been in operation, it was difficult to convince them that the commutators had not recently been turned.

Relative to the term "engineers" as used when referring to the drivers of the electric locomotives, it is in accord with steam road practise, as has been the intention all through. Steam operators will be equally interested with the electrical man in the results and the terms used and comparisons made throughout are meant to be equally clear to both.

Table VI is made up to conform to the usual steam railway locomotive performance sheets and practically the same form was retained for the electric locomotives in order that the comparisons relative to the performance of each might be as direct as possible.

The passenger locomotive miles and the passenger train miles on the Butte, Anaconda & Pacific Railway are the same, as only a single unit is used to haul the passenger trains.

Referring to Table VI, it will be seen that the electric locomotive miles made in passenger service for the six months considered were 43,170, which is approximately 12.5 per cent of the total miles operated by all electric locomotives for the period.

The tractor trucks which are to be supplied with the new locomotives on order for the spotting and switching service will be arranged for coupling onto a standard locomotive unit much as an extra motor car is added to a multiple unit train, except that the electrical connections between the unit and the truck will be such as to connect the motors mounted on the latter in series with those on the former, instead of in multiple as in the case of the extra car in a multiple unit train.

In other words, it will form a three-truck locomotive with six motors, arranged for all six to be operated in series on the usual series points of the controller and with a series-multiple connection consisting of two circuits of three motors each on the usual parallel points.

This plan was considered preferable to adopting a special three-truck locomotive since when the extra truck is detached the unit is interchangeable with all others, or any of the existing units can be arranged for operation with the extra truck by the provision for the necessary electrical connectors.

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APPLICATION OF ELECTRIC MOTORS TO GOLD DREDGES

BY GIRARD B. ROSENBLATT

ABSTRACT OF PAPER

Electric power has been applied almost universally to the operation of gold dredges of late, owing to its convenience and to the fact that hydroelectric power is available at very reasonable rates throughout the western states where gold dredging is carried on. There are a number of different motor applications on the elevator type of gold dredge, which is the type most generally used, and the author considers very fully the requirements of the various drives and the characteristics of the motors suited to the various operations of these dredges. Alternating-current motors are generally used for these purposes and the type of control, which is of special importance, is considered. The paper also gives some figures on the cost of operation of dredges of different capacities.

A GOLD dredge is a piece of machinery designed to dig gold-bearing gravel, sand, or clay, and to treat the material so dug in such a way as to recover the gold contents. It, accordingly, consists essentially of two parts; one the digging part and the other the gold-saving part.

From the point of view of the application of electric power the digging end is of particular interest as the mechanical requirements are severe and the speed control must be exceptionally good. The gold-saving end does not differ very materially as to motor applications from those of the usual metal mining mills, except possibly that the equipment is exposed to a little more abuse and that compact methods of drive are necessitated.

Electric power has been applied quite universally of late to the driving of gold dredges owing to its convenience and economy. Of the $88,400,000.00 worth of gold produced last year in the United States, nearly a fifth came from gold dredges, and in view of the fact that gold is being mined by means of dredges in practically all of the Western States, in most of which localities hydroelectric central station power is available, a few remarks regarding the essential characteristics of successful motor drive may be of interest.

In designing electrical apparatus and applying it to gold dredging, the electrical engineer is often too prone to approach the problem from the point of view that the dredge should be designed particularly to permit of the most favorable application of electrical apparatus. A successful gold dredge is primarily designed to make money. Electric drive is merely an incident in the process, so that, while it is unquestionably often advantageous to modify the ordinary dredge design so as better to accommodate it to the characteristics of the electric drive, nevertheless the fact should not be lost sight of that the electric drive is simply an incident to effect economy and that other considerations are often of greater importance than the most advantageous installation of a particular type of motor in a particular manner.

In considering how electric drive can help the dredge make money, the following factors enter into the total charge against the electric plant:

1. Interest on investment; which is affected by the first cost of any particular arrangement.

2. Power charges; which are affected by the efficiency of the motors and the system of control.

3. Maintenance charges; which are affected by the type of apparatus chosen.

4. Delay charges; which may be very seriously affected by proper or improper application.

As stated above, the gold-saving end of a dredge does not offer any particularly great problems in the application of electric drive. A motor is required to drive either a shaking or revolving screen which removes the coarse rock from the finer gold-bearing sands and gravel. This motor may be either geared or belted to the screen. Gearing is preferable on account of its saving in space, but belt drive is preferable as far as the motor is concerned, on account of the damping effect upon the vibration incident to the screening operations. Squirrel-cage motors are generally used for this purpose and are entirely successful, but some designers advocate motors with phase-wound secondaries in order to reduce the strain at starting. The writer is inclined to favor the squirrel-cage motor on account of its freedom from details which may increase the maintenance charge.

All of the gravel and sand which passes through the screen must be washed in order to obtain the gold out of it, and for this purpose a very considerable volume of water must be pumped on the bridge. Centrifugal pumps are usually used on account of the low head and large volume to be handled, and these are best driven by direct-connected squirrel cage motors. Apart from those features which tend to reduce the maintenance charge, such as adequate insulation, adequate air gap, and adequate bearings, the efficiency of these pump motors deserves consideration, as the amount of the total power used by the dredge used for pumping is very considerable, usually as high as 40 per cent, and sometimes higher.

The tailings, or refuse matter that is sorted out by the screen, must be removed to some distance from the hull of the dredge so that it will not pile up under the hull and strand the dredge. Two methods of taking care of this matter are in use. One, the less common, is to pass the waste down a chute, helping its progress with a stream of water. The other and by far the more common method is to employ a belt conveyer running out of the back end of the dredge for a distance of 90 ft. (27.4 m.) or more, which conveyer is commonly referred to in dredge practise as a "stacker". This stacker is motor-driven. The application is reasonably severe owing to the fact that the motor is usually at the far end of the stacker and, therefore, often exposed to the weather, and also due to the fact that when the stacker has been at rest, considerable torque is required to start it loaded. In cold climates, a stacker when at rest is often apt to freeze, due to the moisture contained in the waste being carried by it. Starting under these conditions is particularly arduous and in some places this trouble is overcome by putting the stacker in a continuous canvas tent like a tunnel and passing steam pipes from a little low-pressure heating boiler up inside this tent. This again makes life hard for the motor because moisture vaporized by the heat of the steam pipes rises to the far end of the stacker where the motor is located, and there often condenses on the motor whenever that machine is shut down and allowed to cool. Accordingly, a motor for stacker service should primarily be designed with adequate insulation to resist continued moisture, and in some cases drip guards have advantageously been placed over the ventilating openings in the motor. Squirrel cage motors with heavy torque characteristics have been used successfully for stacker drive, but the general tendency is to use motors with phase-wound rotors in order to obtain a good starting torque. Here again is the question whether complications of a phase-wound motor are justifiable, and in the writer's opinion it is probably preferable to use a squirrel cage motor designed for good torque characteristics, with possibly a trifle more resistance in the secondary circuit than is found in standard squirrel cage induction motors. A stacker motor is comparatively small as compared with the total motor installation on the dredge, and a slight loss in efficiency on such a small unit is more than offset by a saving in maintenance.

The application of electric power to that portion of the mechanism used for digging is a much greater problem than anything met with in connection with the other applications on the dredge.

There are three distinct types of gold dredges using entirely different digging mechanisms: (a) dipper dredges, (b) suction dredges, and (c) elevator dredges.

(a) The dipper dredge uses a boom and scoop almost exactly like a steam shovel. It is now practically obsolete in the gold dredging industry because of its poor power economy and because the dipper is actually digging dirt during a very small portion of the time that it is in operation. In other words, too much time is lost in lifting the loaded dipper, dumping it, and returning it to the digging position.

(b) The suction dredge is very similar to the ordinary dredges used in harbor and waterways excavations. Its digging end consists essentially of a large centrifugal pump suitable for handling semi-solid material, and is driven by a direct-connected varying-speed induction motor. The suction dredge is applicable for gold mining only in those few localities where water is very abundant and where the gold is found in loose sand. Its application to the gold mining industry is so limited that its details will not be discussed in this paper. It has the particular advantage, however, that its operation is continuous.

(c) The elevator dredge is the most commonly used for gold mining. It is essentially a continuously operating dipper dredge, combining all of the advantages of the steam shovel with the continuity of the suction dredge. A chain of scoops, or " buckets " as they are called, runs over a boom or "ladder," as it is commonly termed. This boom or ladder is swung from a gallows frame or derrick, and by properly manipulating the cables that control it, the boom is held up against the bank to be dug, and the bucket chain driven by a motor, so that each bucket scoops up its fill of earth as it comes round the end of the boom and carries its load without interruption to the mouth of the screen described above Fig. 1 shows the essential parts of an elevator gold dredge as described above. The illustrations on Plate CXIV show some typical elevator dredges and show very clearly the boom, the bucket chain, and the gallows frame from which it is suspended.

Power is required at the digging end primarily for driving the bucket chain, but some power is also required for lifting and lowering the ladder and for operating the devices that pull or hold the dredge up against the bank so that the buckets will bite into their work. Ordinary winches similar to those often used on sea-going vessels are used for these purposes. The duty of the motors is entirely akin to ordinary hoisting service and of very intermittent nature. An intermittent rated wound-rotor motor with high torque characteristics is successfully used.

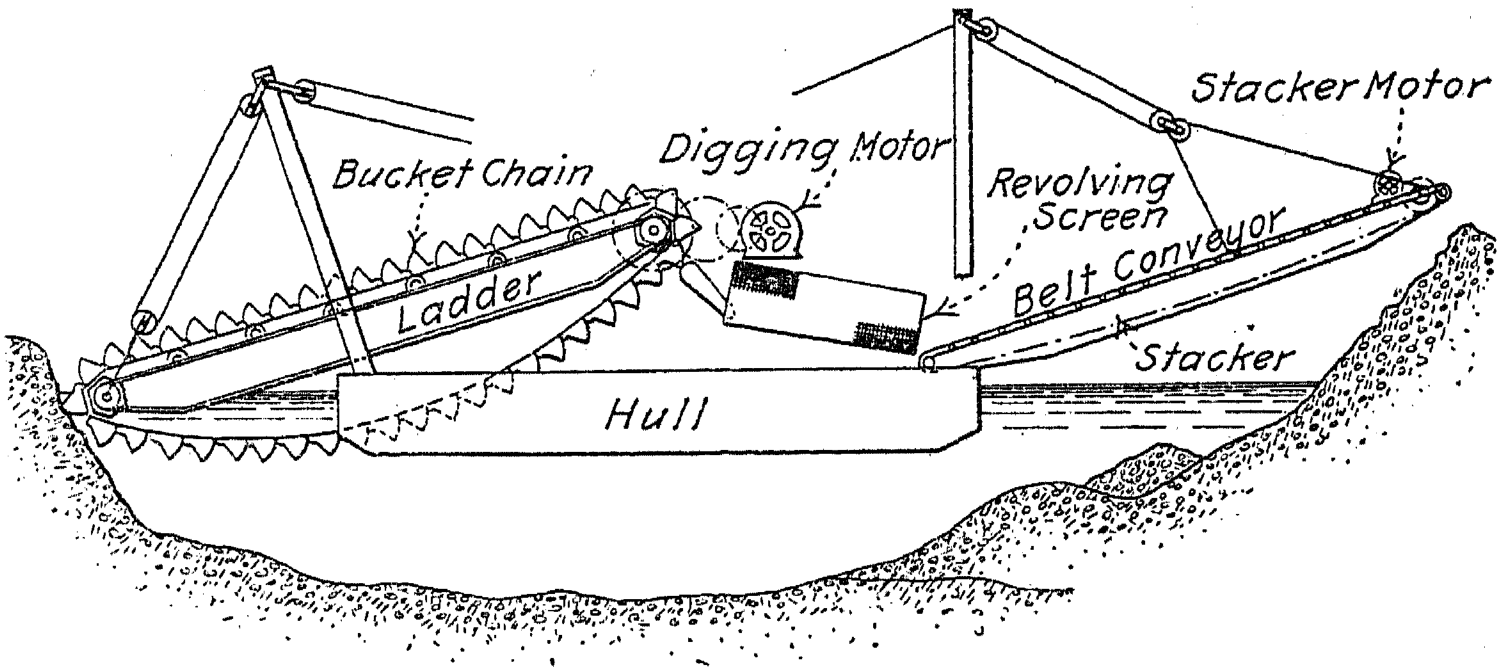


FIG. 1—ESSENTIAL MECHANISM OF AN ELEVATOR-TYPE GOLD DREDGE

The drive of the bucket chain is the real problem on the dredge and no system that has ever yet been devised has proved itself entirely free from all objections. For one thing, power requirements are at times very excessive and vary through a wide range. Accurate speed control is also essential. Good economy is of importance on account of the comparative size of the digging motor compared with the rest of the installation (in this connection it might be stated that the digging notor is usually from 35 per cent to 45 per cent of the total motor capacity on the dredge). Greatest of all is the problem of adequate and successful mechanical connection between the motor itself and the bucket chain.

The power requirements for driving the bucket chain under ordinary conditions may be calculated reasonably closely when the size of buckets, the number of buckets handled per minute, and the type of ground to be dug, are taken into consideration. The following table gives some fairly typical test results:

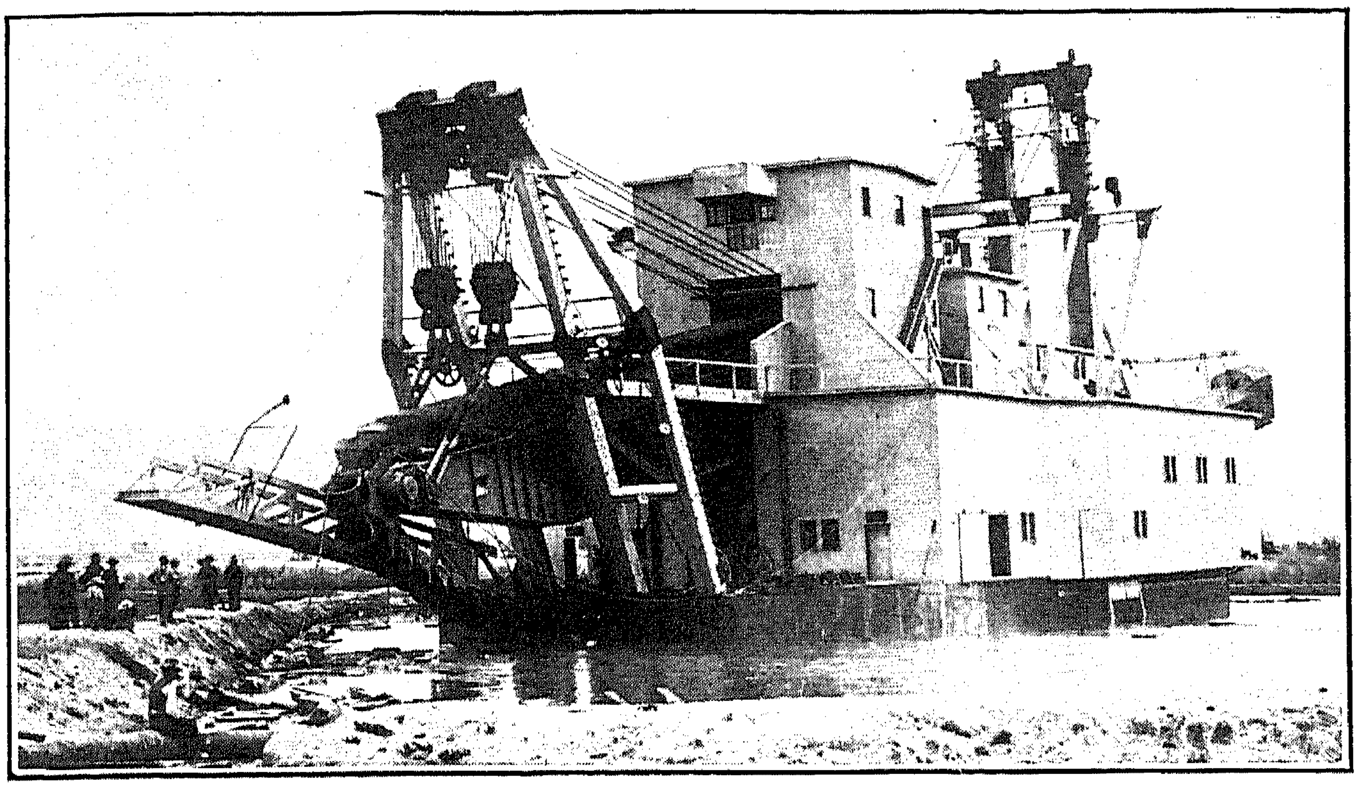
Place	Size of buckets cu. ft.	Buckets per minute	Motor rating h. p.	Average h.p. input
Oroville.............	5	18	75	65
Marysville	7	20	150	140
Marysville	7½	19	200	155
Conrey..............	9	18	150	185
Natoma.............	14	21	400	285
Folsom..............	13½	20	300	202
Boston & Idaho	15	..	300	285 (?)
Conrey..............	17	22½	550	460

N. B. All close-connected chains,—ordinary digging.

However, should one of the buckets in a bucket chain encounter a boulder of larger size than it can handle, the demand on the motor is immediately increased and may even cause the motor to pull out if no protective devices are provided. Also if the buckets run into particularly sticky clay in the course of their digging, the load on the motor may be very much increased, and as such a condition is seldom momentary, the continuity of the overload may burn out the motor unless the speed of digging is reduced.

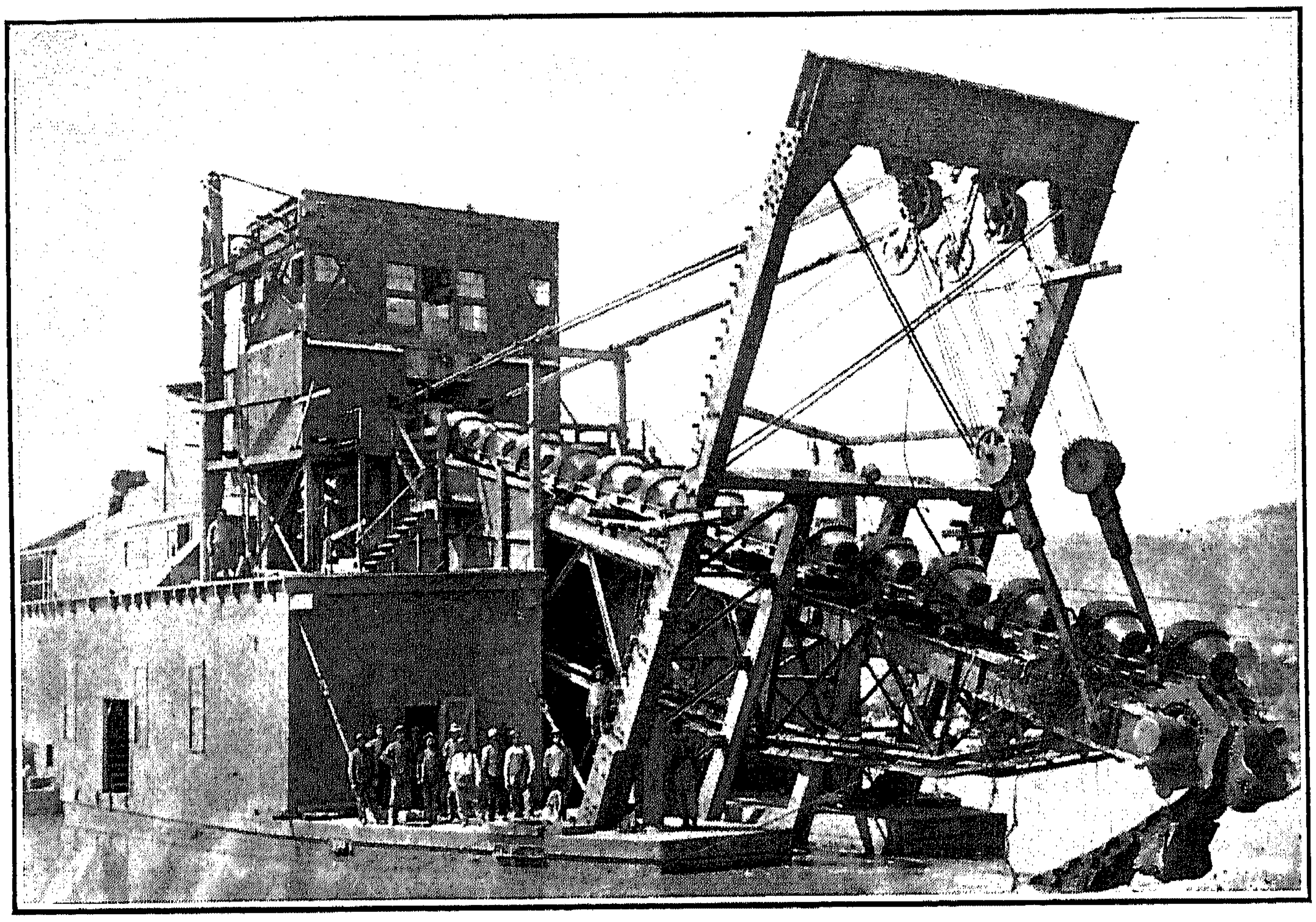
In addition to these requirements, during digging the motor drive must also be capable of revolving the bucket chain slowly at no load for the purpose of repairing the buckets, inspecting the chain, and similar work required for the purpose of mechanical maintenance.

The bucket chain is driven through a hexagonal spindle at the top of the ladder, over which spindle the buckets pass. Each one of the flat sides of this spindle or "tumbler" as it is termed, engages with a corresponding flat side on the under side of the bucket, and the drive is accordingly a positive drive just like any chain drive would be. If the tumbler turns, the bucket chain has got to move or break. It cannot slip. An adequate and successful method of transmitting power from the driving motor to the tumbler has been the source of considerable study by dredge designers the world over. The tumbler shaft usually carries two pinions, one on each side, which engage with two gear wheels carried on a common shaft. This shaft is connected through an adjustable slipping friction to another drive shaft by means of gearing, and the motor drives the last-named shaft. It may be either belted or geared to this shaft. Belting the



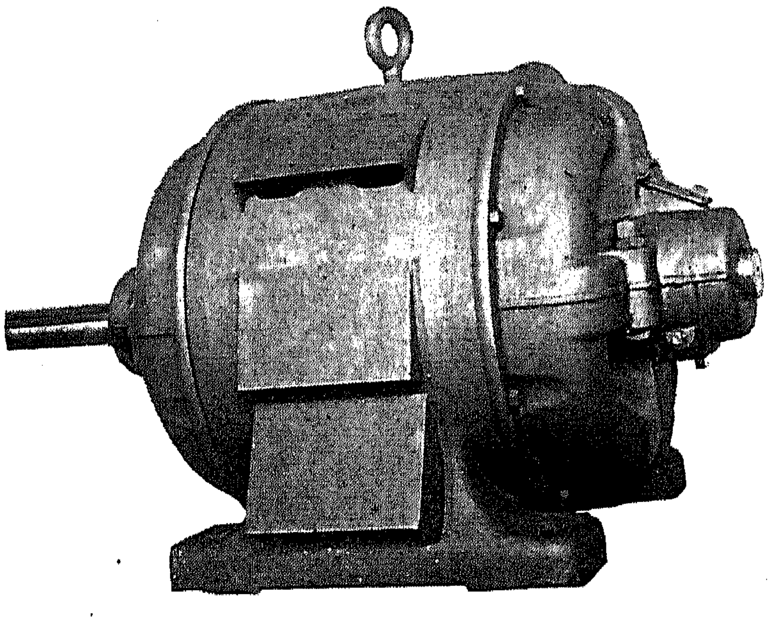
DREDGE WITH 17-CU. FT. BUCKETS. [ROSENBLATT]

Chain is "close-connected", *i.e.* each link of the chain is a bucket. 500-h.p. digging motor and liquid rheostat control; cooling system for electrolyte is visible, dipping into pond at side of dredge.



DREDGE WITH 12-CU. FT. BUCKETS. [ROSENBLATT]

This shows clearly the ladder and the bucket chain. The chain is of the type known as "open-connected", in that there is a link without a bucket between each two buckets.



[ROSENBLATT]

TYPICAL SQUIRREL-CAGE MOTOR, WITH SPLASH-PROOF COVERS, FOR STACKER DRIVE.

motor is of course the easier on the electrical apparatus, but on the other hand has certain disadvantages. A very large and expensive belt is required on account of the tremendous torques involved. There are sometimes difficulties due to maintenance, because of the moisture that is often present on board a dredge. The belt sometimes slips just when maximum torque is wanted. Occasionally, under the heavy stress due to the slipping friction having rusted, a belt will break. Also a belt transmission for the transmission of the torques involved takes up considerable space, and space on a dredge is valuable.

On the other hand, gearing, while economical in space and entirely positive in action, has the disadvantage that it imposes very severe service on the electrical equipment, in that every strain and every vibration from the bucket chain finds its way back to the revolving part of the motor. Flexible couplings have been tried between the motor and the driving gear but without success. The large variations in torque met with, sooner or later ruin any type of flexible coupling that has as yet been tried. The gear drive has, however, proved entirely successful where a motor has been secured that will adequately withstand the stresses. Of the two methods, belt vs. gear drive, each has its ardent devotees.

From a consideration of the above, it will be seen that the motor required for digging service on an elevator dredge must have the following characteristics:

(a) It must be varying-speed machine; and if in addition it can be made an adjustable-speed machine this would be a considerable advantage.

(b) It must be capable of being revolved at light loads and very low speeds.

(c) It must be capable of developing a maximum torque, at any speed from zero to approximately full load speed, of several times its normal rated torque.

(d) It must be capable of carrying for prolonged periods of hard digging a torque overload of approximately 25 per cent at a speed reduction of probably 25 per cent.

(e) It must be of substantial mechanical construction, particularly as to shaft and bearings, in order to resist a very heavy belt pull when belt drive is used, or repeated shocks of severe gear thrusts when gear drive is used.

(f) It must be reasonably efficient.

In order to obtain all of the above characteristics, it has often been suggested that a direct-current motor of the type used in steel mills, with possibly variable-voltage speed control, might prove advantageous for digging service on big gold dredges. However, every investigation that has been made (to the writer's knowledge) of this matter has developed the fact that the losses in efficiency due to the conversion from alternating current to direct current practically offset the advantages gained by more flexible control under the ordinary cycle of operation, and further, the first cost of such an installation is prohibitive, considering the ordinary life of a dredging venture. In this connection it might be stated that while there are exceptions, the average dredge is about worn out at the end of ten years, and will then require either complete rebuilding and remodeling or will operate with so many shut-downs due to breakages and the like that rebuilding or scrapping will prove most economical. Accordingly any installation more expensive than ordinary must show a saving that will repay the extraordinary expense in 10 years, and this no combination of direct-current equipment has as yet been able to show.

Accordingly the only type of motor left available is the moderate-speed wound-rotor induction type, and for the most successful application the motor should be designed with special reference to the work it has to do.

From experience with the troubles of a dozen dredges, large and small, the writer would recommend specifications embodying the following:

(1) The motor should be capable of carrying its rated load continuously with a rise not to exceed 40 deg. in any part.

(2) The motor should be capable of developing a torque 25 per cent in excess of its rated full load torque at a speed of 75 per cent of its synchronous speed for a period of two hours with a rise not to exceed 55 deg.

(3) The motor should have a maximum torque and a starting torque of not less than 2 1/2 times its full-load torque.

(4) The shaft shall be of such material and dimensions that strains due to the developing of maximum torque shall not appreciably affect the dimensions of the air gap on any side of the motor.

(5) The bearings shall be designed to resist an upward thrust, and shall preferably be of the design known as rolling-mill bearings, furnished with stud bolts and lock nuts instead of the usual design employing cap screws.

(6) The lubrication of the bearings shall be adequate. On motors of 200 h.p. and over, at least two oil rings per motor

bearing are recommended. On motors of 500 h.p. and over, the use of gravity feed lubrication should be considered.

The problem of control of large motors used for digging service on gold dredges would be more simple if direct-current motors could economically be used. As, however, their use is impractical, the control for a-c. motors that most nearly approaches direct-current control is desirable. The control must permit reversing the direction of the motor, principally to permit the bucket line being backed away from obstructions. For service during the repair of the bucket line, small variations in speed should be obtainable, particularly at partial loads. A control permitting continued running at low-speed points is particularly necessary.

For small motors on little dredges, say employing a digging motor of 100 h.p. or less, the ordinary drum-type controller proves adequate. For larger installations a combination of magnet switches controlled by a master controller has been used in a large number of installations, but for the larger motors the ideal control seems to be the liquid rheostat.

Magnet-switch control has been used satisfactorily on a considerable number of dredges employing digging motors as large as 400 h.p. The very large fleet of large dredges operated in California by the Natoma Consolidated mostly employ magnet-switch control on dredges having digging motors of 300 h.p. and larger. It has, however, several distinct disadvantages for dredge service. The principal disadvantage is that only a limited number of definite points is available with this type of control unless the number of magnet switches in the secondary circuit is made very large, which in turn makes the controller inordinately expensive. Therefore, small variations in speed, particularly at light loads, are not available with this type of control, and in order to obtain slow movement of the bucket chain, it is customary to start the motor up and then plug it, with consequent strain on all mechanical parts, as well as wear on the control contacts. Further, this type of control does not allow the dredge operator to pick out any particular speed at which he desires to run. He can only pick a particular point on the controller and the corresponding motor speed will depend on the torque being exerted by the motor.

Another disadvantage of this type of control is the tremendous amount of resistance required for a large motor, as the resistance must be sufficient in amount to permit very low motor speeds at light loads, and large enough in capacity to permit continuous operation at reduced speeds with heavy torques. This makes a very bulky resistance and unless the resistance is large enough there is considerable danger of the overheating of the grids starting a conflagration.

The liquid rheostat for digging motor control has, on the other hand, none of the disadvantages of the magnetic switch control. There are no definite steps, and the speed of the motor may be varied by infinite gradations. The operator simply moves the rheostat handle until he obtains the speed he desires. In other words, he does not work for any particular point on the rheostat, but works simply with the idea of getting the speed he wants. For large motors, the liquid rheostat and its accessories take up much less room than would a corresponding magnetic switch control and its attendant resistance, and there is never any danger of the electrolyte used (water and common washing soda) causing a conflagration.

However, the liquid rheostat for use on dredges must be modified from the forms commonly used for hoist service and the like on land. The first liquid rheostat installed on dredge service was on one of the Natoma dredges with a 400-h.p. motor, and while it was operative, it was not entirely satisfactory, because certain essential details of design and application were overlooked. A very similar liquid rheostat on which these details have been given due attention is now being used on one of the dredges of the Conrey Placer Mining Co., and has been entirely successful and satisfactory in operation with a 550-h.p. digging motor, which I believe is the largest digging motor on any elevator type gold dredge in operation today anywhere.

In order to keep down the size of the liquid rheostat for this work, it is practically necessary to provide some means of artificial cooling for the electrolyte. Usually this is accomplished by circulating cooling water through coils in the rheostat tank. On the Natoma rheostat the mistake was made of pumping water from the pond in which the dredge floats, through these cooling coils. Due to the operation of the dredge this pond water is usually pretty muddy, and often carries a large percentage of solids in the shape of silt. At Natoma this silt coated the inside of the cooling pipes, thus reducing their effectiveness and eventually clogging them up, necessitating a shut-down while they were blown out with compressed air. Shut-downs on a dredge cost money, because to realize the greatest return on the investment, the dredge must be digging all the time. Therefore this eature made the Natoma rheostat undesirable. At the

Conrey Placer Mining Company's property, the cooling system consists of a series of pipe coils immersed in the pond, and the electrolyte is pumped from the rheostat tank through the coils and back again, instead of pumping pond water up to the tank and through coils installed therein. There has never been a shut-down on the Conrey dredge due to the rheostat or its cooling system. The motion of the dredge in the pond is sufficient to keep silt from settling on the cooling coils.

Another point that was overlooked on the Natoma installation was the fact that dredges swing, and often rock considerably. This causes the electrolyte to splash out of the rheostat. Usually such loss by splashing was replaced by pouring in additional water, but this of course changed the density of the electrolyte and caused the operators some trouble. On the Conrey rheostat baffle plates and enclosing covers were supplied, which effectually prevented any splash.

Another trouble that was experienced at Natoma was that, due to deficiencies in the cooling system mentioned above, the electrolyte very often attained a very high temperature during hard work, which caused excessive evaporation. Under certain conditions this evaporation was so great that the annoyance and expense of bringing the amount of fresh replacing water required on to the dredge and filling the rheostat was considerable. This trouble has been obviated at the Conrey installation by having an adequate cooling system.

All in all, it may be said that for large digging motors of say 350 h.p. and up, the liquid rheostat makes an ideal method of control, provided the rheostat is of adequate mechanical construction for the service and is provided with a proper and sufficient cooling system. Both liquid rheostat and magnet switch control may be arranged to give the same advantages as to protection against acceleration at too high a rate and against excessive overload due to sudden changes in speed.

It will probably be gathered from the above remarks that the successful application of electrical apparatus to gold dredging operations depends on a multiplicity of details, each of which may be of comparatively minor importance in itself, and this is true. With the areas that are now still available for dredging, a multitude of small economies must be practised in order to make the process commercially successful. When it is considered that many dredges dig for about four to five cents per cu. yd. and that the gold contents of the ground often run as low as seven cents per cu. yd., it can readily be seen that a matter of one cent economy or waste may make or break the concern doing the dredging. Therefore maintenance deserves consideration. But most of all, freedom from shut-downs is of prime importance. The dredge cannot make any money while it is not digging; but, interest, not only on the money invested in the dredge, but on the money invested in the purchase price of the land that is being dredged, goes on just the same, and therefore shut-downs must be avoided at any reasonable cost, and this should be particularly borne in mind in the selection and application of the electrical apparatus and its control.

A digging motor that may be of sufficient capacity, but cannot be adequately controlled, may break a bucket chain and put the dredge out of business for 24 hours. Ordinarily, dredge operators figure on operating 24 hours a day 365 days a year and a fair average is to expect the dredge to be actually performing its operations for 85 per cent of the total time.

On account of the high load factor, and on account of the comparative uniformity of a large percentage of the load, as well as on account of the comparatively large blocks in which the power is purchased, dredges make a particularly attractive load for hydroelectric central stations, and a few figures as to the power consumption of dredges may be of interest in this connection.

Moderate-size dredges with buckets of about 5 to 7.5 cu. ft. capacity will handle from 60,000 to 100,000 yards per month, at a power consumption from 1¼ to 1¾ kw-hr. per cu. yd.

Larger dredges with buckets up to 15 cu. ft. capacity will dig from 125,000 to 250,000 cu. yd. per month, and will take from 1 to 1 1/2 kw-hr. per cu. yd.

The very large dredge of the Conrey Placer Mining Co. mentioned above, which has buckets of 17 cu. ft. capacity (I believe the largest in the world) has handled 520 cu. yd. of material per running hour. Including delays, this means 325,000 cu. yd. per month. Handling material (heavier than usual) weighing 3000 lb. per cu. yd., its power consumption was 1.28 kw-hr. per cu. yd.

The above figures are total power taken by the dredge for all purposes. The power taken by the digging motor is about 40 per cent, on an all-day average, of the total power. From such test results as are available, the power for digging seems about proportional to the yardage dug, *i. e.*, the kilowatt-hours are proportional to the yardage handled times the number of hours during which it was dug.

DISCUSSION ON "APPLICATION OF ELECTRIC MOTORS TO GOLD DREDGES" (ROSENBLATT), SPOKANE, WASH., SEPTEMBER 11, 1914.

Ford W. Harris: The problems so clearly defined by Mr. Rosenblatt are, in general, those that confront any engineer proposing to equip rough heavy-duty machinery with motors. As electrical engineers we are in duty bound to give electric power the benefit of every doubt when the expediency of a given installation is considered, but that the application of motors to dredges, shovels, and the like, is a hard problem must be understood at the outset. It is primarily a problem of applying a constant speed, constant maximum torque motor, to a variable speed, variable torque load. More particularly it is the application of a constant torque driving means to a variable torque load. We have the problem of a widely variable load that must be economically handled regardless of the speed. The operator wishes to operate the major portion of the time at constant speed with a fairly uniform load. At times this load is enormously increased and at times he desires to greatly reduce the speed for repairs, etc. In general, as far as satisfactory operation is concerned, the enormous pulls occasionally needed may be and preferably should be exerted at a low speed, so that the actual power requirements may be fairly constant.

Obviously what is needed is means for connecting the load and the motor in variable speed ratio, the problem being very similar to that solved by the change gears of an automobile. Obviously, also, no such mechanical means has been devised which will handle the very variable shocks and strains incident to transmitting 500 h.p. to such a load.

The method by which Mr. Rosenblatt has solved the dredging problem is open to certain very obvious objections. Speed control by liquid rheostats involves at the outset large energy losses, the rheostat being primarily designed for such large losses. Motors having the mechanical and electrical characteristics outlined are expensive and heavy. It should be remembered that when a wound-rotor motor has its speed reduced by the insertion of external resistance there is no increase of torque but merely a decrease of speed. The power output of the motor is reduced with the speed. This is only a partial solution of the problem.

I have personally figured many installations of large and small motors for hoists, shovels, and the like, and I believe that a serious mistake is made in applying a-c. motors to work of this kind. Particularly I think that the application of the a-c. motors of any kind to digging service on a dredge is poor engineering. Here you need a moderate torque at a high speed and a much larger torque at a correspondingly reduced speed. The larger companies have made many installations of a-c. motors for such service and made them stick, but it is significant that most large mine hoists are operated by d-c. motors, through the Illgner system, and that our street cars still run largely with d-c. motors in spite of persistent efforts to enlarge the number of single-phase installations. It is further to be noted that the single-phase railway motor has series motor characteristics, and that few installations of induction-motor-driven railways have ever been seriously attempted in this country. If it is not feasible to operate a railway car, which is an approximately constant load at variable speed, with induction motors, how much more hopeless it is to operate a gold digger which requires large torques at times when the speed may be reduced to keep the power input fairly constant.

To my mind there is no good way to drive such a load from a constant-torque motor. The load is one that requires series motor characteristics. If there were available single-phase series motors which could be bought at a reasonable price and maintained at a reasonable cost they might be used in this connection. Barring such motors the proper system would be the application of a double or quadruple equipment of series d-c. motors in combination with a d-c. generator—a-c. motor set.

With such a multiple motor drive and proper series-parallel control it would be possible to operate on a variable torque basis and get fine results, the motors running four in multiple under normal conditions and being thrown in series for heavy pull-outs at low speeds. The power economy would be high and with proper cut-outs on each motor the reliability factor would be increased, as three motors could be used to operate in an emergency. While the first cost of the motor equipment would be high, the greater flexibility and reliability of the equipment would result in greater output at the dredge, which would soon wipe out the additional investment.

M. H. Gerry, Jr.: I am glad to say a word on this paper because there is much of interest in connection with such a machine as a gold dredge. This paper is a further demonstration of the great flexibility of electrical power and the wide diversity of its application. I disagree with the statement made by some one in the discussion, that there is any difficult principle involved in this application of electrical power. The problem is to ascertain in advance, the actual conditions of operation, and in this respect it does not differ from electrical traction or the thousand and one other applications of electrical power. Once these conditions are fully understood, the difficulties very largely disappear and are then only those quite commonly met with in solving mechanical and electrical engineering problems. However, it requires much study and time to analyze a problem of this kind, and it is here that the skill of the engineer is required.

It has been my good fortune to have some connection, in an engineering way, with the dredges which form the subject of Mr. Rosenblatt's paper. I was familiar with the situation from the first, when the dredges then in operation were driven by steam engines. These older dredges have all been rebuilt and are now operated by electrical power, but the dredge which forms the special subject of Mr. Rosenblatt's paper, is a later installation and was designed originally for electrical operation. The problem at first presented was that of the general advisability of applying elecrical power to the operation of dredges in this situation, and it was a question on which engineers differed. The ground was hard, there were many large boulders and the bedrock was at great depth. The steam dredges were experiencing much difficulty, and the power was insufficient for the work and there were constant breakdowns and delays. A very able engineer who was called into consultation, was of the opinion that the conditions were altogether too difficult to permit of operation by electrical motors. The ever-varying pull on the digging chain, the frequent obstructions met with in the way of boulders and other causes, tended to produce enormous strains and varying torque on the driving motor, and render questionable the successful operation by electrical power. Those who have seen a dredge of this kind operating in hard ground will appreciate how difficult the problem appeared at that time. One engineer observing the operations, used this expression, "see it toil, see it toil;" the inference being that the "toil" was altogether too strenuous to be undertaken by an electrical drive. That, however, is now all history, and we know that for any dredging service, no matter how difficult, electrical motors properly designed are altogether suitable. The dredge is a comparatively simple machine; as here applied it is a combination of elevator and excavator. At times there is very little actual digging, as the earth is loose and falls into the buckets. Under these conditions it is merely a question of elevating this earth to the surface. As the excavation reaches bedrock the conditions change; the material is hard and tough and must be torn apart with the expenditure of a considerable amount of energy. From my knowledge of conditions at Ruby and elsewhere, I would say that the dredge operations for the machine described by Mr. Rosenblatt, are the most difficult in this country. This hard digging, the great size of the dredge and the depth from which the material was excavated, were the conditions surrounding the problem for this particular dredge. The bucket chain is a massive affair and it moves at a slow rate of speed. The pull on the bucket chain is constantly varying, due to the ever-changing conditions of digging, and also to the further fact that the chain is driven from the top by a five-sided tumbler, resulting in a constantly varying driving radius. The motor torque is, therefore, ever changing and may vary widely during short intervals of time.

One of the important conditions of dredge operations is to maintain maximum speed of the digging chain in the upper part of the excavation and to be in readiness to develop maximum pull on the chain, at somewhat lower speed, as soon as bedrock is reached and the difficult ground encountered. It follows, therefore, that a considerable measure of speed control is absolutely necessary for successful operation in this situation. Many methods of obtaining this speed control have been suggested and applied, but the one described by Mr. Rosenblatt has proved eminently successful for conditions met in actual service. Some engineers have suggested a change to a direct-current drive, but I have never been able to obtain any better efficiency or improved performance for direct current, where the available source of power was alternating current, and the necessity existed, therefore, of using conversion apparatus. At the present time there is nothing better or more available for this service than an alternating-current motor having a wound secondary with a control rheostat capable of continuous operation.

Mr. Rosenblatt has well said that for the best results it is necessary to keep these dredges in as continuous operation as possible. When the records show that month in and month out the dredges have been in service 80 per cent of the total time, it is certainly a creditable performance. Such results as this prove that electrical power, when applied to dredge operations, is a great success, and that the apparatus as described by Mr. Rosenblatt has materially contributed to this result.

Some discussion has arisen in reference to the relative merits of a belt drive as compared with a direct gear drive for the main bucket chain of a dredge. This is a question more of expediency and economy than of performance. It is not well to make the drive too rigid, and some means of providing for a little slip in case the buckets come up against a rigid obstruction, is very desirable. With a small or moderate-size dredge, this result can be obtained in a rather inexpensive way by using a belt drive from the motor and permitting the belt to slip if occasion should arise. On very large dredges, however, belts are too bulky and are very objectionable for mechanical reasons, and it is better to provide a gear drive with a form of mechanical slipping friction introduced at some point between the motor and the bucket chain. This slipping friction should be designed, not as an ordinary friction clutch, but as an actual slipping friction.

To return to the matter of control for the main digging motor, and referring especially to the liquid rheostat described by Mr. Rosenblatt, I would like to add that this has proved to be a most satisfactory piece of apparatus. For hours at a time the motor is operated at reduced speed and the heat developed in the rheostat is taken care of very nicely by the cooling coils. The regulation is excellent and the man operating the dredge has fine control over the bucket chain. For motors on small dredges, almost any kind of rheostat will work well, but for such an immense dredge as the one here described, I know of no better arrangement than the liquid rheostat. The arrangement whereby the cooling coils are placed on the outside of the boat in the dredge pond, is worthy of special attention. This device has obviated all the trouble with the circulation of muddy water through cooling coils immersed in the rheostat tank, and is one of the reasons for the success of this installation.

In conclusion I would like to emphasize the thought which I first mentioned; that it is not at all difficult to apply electrical power or electrical methods to the operation of any machinery if the conditions be carefully analyzed in advance, and the proper use be made of methods and machinery now well understood.

F. A. Ross: I am conscious that a mining engineer can take but small part in this discussion of Mr. Rosenblatt's paper. The word "mining" can scarcely be applied to gold-dredging since, as Mr. Gerry has said, dredging is but the elevation of gold-bearing gravels and a transfer of the same to another point; therefore, the design and operation of dredges comes within the province of the mechanical, electrical and, often, the hydraulic engineer, rather than in that of the mining and metallurgical engineer. The latter is called into the question only at the beginning and at the end. Because of his training in estimating the value of mineral-bearing ground he does the drilling or sinks the test-pits and then he estimates the profits possible, or probable, from a handling of the greatest tonnage practicable.

At this point he must turn for help to the mechanical engineering departments of the dredge-builders, where the data he submits govern the design of the dredge; and the mechanical engineer, himself, must apply to the electrical engineer for motor designs and for advice as to the general application of electricity to the needs of the case in hand. But the mining engineer must make no mistake as to the average character of the gravel to be worked nor may he fail to note the heaviest duty that the dredge must perform. Moreover, as a metallurgist he must specify the type of gold-saving apparatus to be used, but, once the machine is built and at work, he may safely step aside and leave its operation to the skilled dredge-crew that takes orders henceforth from the mechanical and electrical engineers. Electricity has so far superseded steam as a motive power in dredging that there are few steam dredges employed today in working gold-bearing gravels.

As Mr. Gerry said, the latest gold-dredges are mechanical monsters, performing feats of strength and endurance that are almost unbelievable by those that see them for the first time; and they call for a refinement of theory and practise both in mechanical and in electrical design. The close-connected buckets must tear away at consolidated beds of boulder-gravel without pausing and must work out of sight, under water, at depths of 70 feet or more. Gravels differ greatly in character, some being composed of small, nearly uniform, boulders, while others contain boulders of all sizes, even up to a size that renders dredging impossible.

The greatest difficulty, then, lies not so much in the building of a machine strong enough to stand up to the duty imposed upon it, as in an accurate determination of the total work to be done and the character of that work. Mr. Rosenblatt mentions a maximum capacity of about 250,000 cu. yd. per month for the largest gold dredges, but there is one up in Idaho Basin which, according to the statement of its general manager, made a record of 340,000 cu. yd. in one exceptionally good month. In this case, the gravel is small and uniform and the beds shallow.

L. K. Armstrong: After what Mr. Ross has said I don't think it will be necessary for me to say anything or to apologize for the little the mining engineer knows about gold dredges.

I have in mind the early days when the electrical engineer was seeking a market for his current. Some of them conceived that they might apply it to the gold dredge business, and after a considerable time and many attempts they seem finally to have acquainted themselves so thoroughly with the business that the business has been practically turned over to them.

I was trying to think, while one of the speakers was talking, about a meeting of the American Institute of Mining Engineers, when this particular subject was brought up and there was a lot of discussion on the question of whether or not electricity could ever be applied successfully to the operation of a gold dredge; the discussion was all in favor of the negative. Today from the information we have here, I find that gold dredging would be practically unsuccessful, and I am very certain that is so in many cases, but for the application and practical developments on the part of electric engineers and the application of electrical power.

W. M. Shepard: In regard to the case of squirrel-cage vs. slip-ring motors for screen and stacker drive. All of the earlier California dredges were equipped with squirrel-cage motors and it is only on the larger dredges built in the last few years that slip-ring motors have been used.

On large dredges the screen represents quite a heavy starting load, especially if it is started when full of wet clay and rocks, which very often happens. The screen is operated continuously when the dredge is in operation, so that the characteristics desired are good efficiency and high starting torque.

On large dredges for deep digging, the stacker is very long and elevates the material to a considerable height; this is necessary to get the large amount of material handled out of the way. On the Yuba Consolidated Goldfields dredge No. 14, which digs to a depth of 70 ft. below the water line, the stacker is 137 ft. long. Starting a stacker of this kind, especially if it happens to be loaded, as is frequently the case, requires a high starting torque and it sometimes takes several minutes to bring it up to speed.

If a stacker of this kind was operated by a squirrel cage motor of ordinary design it would require a larger motor than if the slip-ring type was used, on account of the lower starting torque.

A squirrel-cage motor with high-resistance rotor could be used which would give the required starting torque, but at the sacrifice of efficiency, and as these motors are large size, those on some of the larger dredges being 75 h.p., and operate at all times that the dredge is running, this loss in power even at a low rate would become quite an item. With some dredges where a considerable number of small boulders are handled over the stacker, the speed has to be reduced at times when a number of these are being handled, as, if the speed is too high, the boulders will not stick to the stacker belt and be carried over the top, but will roll down and cause considerable trouble. A slip-ring motor with proper resistance would take care of a case of this kind when a squirrel-cage motor would prove unsatisfactory.

The difference in maintenance cost between the slip-ring and the squirrel-cage motors used on these drives is shown on actual operation to be negligible; for the slip-ring motors occasional extra brushes are required, and for the squirrel cage, extra contacts for the starters.

The drum-type controllers used with these motors give practically no trouble as the service required of them is comparatively light.

Regarding Mr. Rosenblatt's recommendations covering specifications for the digging motor: it seems to me that the introduction of the special features which he recommends is confusing and not to the advantage of the purchaser. For instance, a motor designed to meet the standard heating guarantees adopted by all American motor manufacturers from the A. I. E. E. Rules would, in all probability, meet the specifications submitted by Mr. Rosenblatt and the use of standard specifications would be of advantage to both the purchaser and manufacturer. Furthermore, it is not usually necessary for the digging motor to run for considerable periods at reduced speeds. The rate of digging can be controlled either by changing the speed of the bucket line (varying the speed of the digging motor) or by varying the rate of feed, which is controlled by the swing winch.

The dredge has side lines on either side connected to deadmen on the bank. The swing winch in connection with these lines swings the dredge back and forth across the face of the cut while the bucket line is in operation. The rate at which the dredge is swinging governs the feed of the buckets and so the amount of material moved and the load on the digging motor.

It is much more efficient to allow the digging motor to operate at full speed with all resistance cut out of the secondary and control the load by means of the swing winch motor (which is from 10 per cent to 15 per cent of the capacity of the digging motor), than to operate the digging motor at reduced speed with consequent losses in the secondary resistance.

In regard to special bearings in the digging motor to resist upward thrusts, the large majority of gold dredges have the digging motors belted, which requires no special features in the bearings. The larger motors are usually provided with three bearings.

Regarding those motors which are geared: the bearing thrust when digging should be downward; the only times when the bearing thrust should be upward would be when the bucket line was being backed up, which would be only a very small fraction of the time it was going ahead, and when it was being backed up the load would be light, as there would be no digging.

The point which I wish to bring out is that standard equipment, if properly applied, is well adapted to meet all conditions of dredge service. I have had to do with the electrical equipment of something over thirty gold dredges of bucket capacities ranging from 3 to 18.2 cu. ft. and digging depths of from 15 to 70 feet. These dredges operate in every character of ground and all use standard equipment. Among them are some of the most successful dredges yet constructed. The problem in electric drive is in proper application and not special equipment.

Regarding the control of the digging motor, I believe that proper drum-type controllers are all that is required for motors up to 200 h.p. capacity. There are quite a number of digging motors of this size operating with drum controllers and they have proved entirely satisfactory. A number of them have been in operation over a period of years. The control is adequate and simple and the maintenance cost very low.

Drum-type control has been employed on digging motors as large as 300 h.p., but in the writer's opinion better service could be obtained with other types of control for motors above 200 h.p.

For larger motors magnetic control or properly designed liquid rheostats can be used. There are a number of magnetic control equipments in successful operation on digging motors of 300 h.p. and 400 h.p. capacity, some of which have been in operation for two or three years. They have all proved satisfactory in operation and their maintenance cost has been low.

While experience with liquid rheostats on board dredges is as yet very limited, and there are some difficulties to be overcome, there is no reason why, with proper design, their operation should not be successful.

I cannot agree with Mr. Rosenblatt regarding the excessive amount of resistance required with magnetic control nor with his statement regarding the fire risk incident to the use of resistors. The digging motors are provided with standard heavy duty resistors good for continuous operation at a speed reduction of fifty per cent, and these have proved entirely adequate; and in no case that I have ever heard of has there been any question of fire risk from these grids and there need not be, if they are so located that the air can circulate freely about them.

There have been a number of fires on dredges caused by electrical troubles; these, however, have nearly all been due to faulty installations of oil switches. As a result of these fires the Board of Fire Underwriters of the Pacific made a thorough investigation and issued a set of rules on "Standard Electrical and Fire Protection for Dredges." This set of rules is very thorough and in them no question is raised regarding the grids nor are special precautions required in their installation.

Mr. Rosenblatt mentions the use of intermittent-rated motors for ladder hoist winch, and for raising the spuds or controlling the head lines, if these are used instead of spuds; if separate motors are used for these purposes the intermittent-rated motor would be all that is necessary. As a rule, however, separate motors are not provided for this service. The ladder hoist winch is usually operated from the digging motor and this arrangement provides so much power that the ladder is raised much more quickly. The control of the spuds or head-lines is usually taken care of by the swing winch motor.

These operations are controlled by levers in the winch room. The swing winch is in operation all the time and an intermittent-rated motor is not suitable for this purpose.

The power required from the digging motor depends on the size of buckets, speed of buckets, depth of digging and character of ground dug. The size of buckets varies from 2½ to 18.2 cu. ft., the speed from 18 to 22 buckets per minute, the depth from 10 to 70 feet below the water-line, and the character of ground from loose gravel and sand to hard cemented gravel. The size and weight of a dredge does not depend simply on the size of the buckets, but is also governed by the depth of digging and character of ground.

The largest and heaviest gold dredge yet constructed is, I I believe, one of the all-steel California dredges which has 16-cu. ft. buckets and digs to a depth of 70 ft. below the water line. This dredge has handled 325,000 cu. yd. in a running month of 30 days. I believe the highest record for material moved is at present held by the Boston and Idaho dredge, which has buckets of 18.2 cu. ft. capacity and has a record of over 400,000 cu. yd. in one month.

In point of size and power this dredge is not the equal of the large California dredge just mentioned, but has shallower ground and easier digging.

A. A. Miller: I do not have anything in particular to add to the technical part of this discussion, but I know that a great deal of the work of this character, the use of electric power in gold dredging, is being carried on in the northern possession of our Canadian neighbors across the line, in the vicinity of Dawson, Yukon Territory, particularly; they have some of the largest gold dredges in the world, I believe, which are being used, particularly by Mr. Boyle of the Boyle Concessions; they have built water power plants and transmission systems of their own for the purpose of furnishing these dredges with electric power. Unfortunately the site of operation is so far removed from us that we cannot get to them very frequently to know what they are doing, and the information apparently does not reach us. It would be interesting if we could get more detailed information from those particular dredges.

I believe there will be also in the course of the next year or so considerable activity in the vicinity of Nome in this same sort of work. I was told by a mining engineer who is familiar with conditions there that in the next two or three years there will be something like $5,000,000 taken out from a clearly defined area by dredging operations.

C. B. Rosenblatt: I am going to make this discussion as brief as possible, but there are a few things that I can't let go by. One of the gentlemen registered some objection to the use of alternating current. We all know that a direct-current motor would be an ideal drive. Nobody denies that; but the gentleman does not look at this matter from the dredging point of view, he looks at it purely from the electrical engineer's standpoint, and that is one thing I particularly ask you gentlemen not to do when it comes to dredging. Direct current for dredges has been figured over and over again. I believe Mr. Gerry here went into that as carefully as any man possibly could when the Conrey Placer Mining Company decided to electrify. Engineers in California went into it carefully too. It can't be figured out any way to show a monetary profit under conditions of power supply that obtain today—and remember the dredge is in business to make money.

Mr. Shepard has a very good communication from San Francisco. There is only one thing about it that demands comment and that is that it represents California practise as advocated by two manufacturing companies. Mr. Shepard's remarks apply particularly to the type of dredge built by those two companies, which use certain motor drives that are arranged primarily for the use of standard motors, even for the digging motors. There is considerable question as to whether the drives used by these manufacturers are the best for a big dredge, but that is not a problem for the electrical engineer to discuss. Mr. Shepard mentions particularly the use of a wound-rotor motor drive for the stacker as compared with the squirrel cage motor. That is a matter on which I said I expected some criticism from California because they have generally come to use the wound-rotor motor for that work. But remember the California climate is particularly favorable. It is all right to take a slip-ring motor and stick it up on the end of the stacker if you have a favorable climate and never get down below forty degrees above zero, but the conditions in Montana, Oregon, Wyoming and Alaska are different from that. Another thing Mr. Shepard does not take into account is the fact that the dredges with which he is concerned, have comparatively easy digging; while the Californians may not agree, I believe it is easier to dig the California gravel than it is the Northern clays, and Mr. Gerry brought that out when he said that his own opinions and observations in this matter had been backed up by the observations of practical dredge men.

There are good points about each kind of drive. Each may be particularly fitted for a particular installation. There is no panacea for this dredge work. I have tried to point out the considerations that apply most generally. We have to analyze each case by itself and find the underlying conditions that make the selection of particular apparatus most desirable, and while unquestionably, for Mr. Shepard's own conditions, he has selected very excellent electric drives for those dredges in California, they will not necessarily work with best success everywhere in the world.

Presented at the Pacific Coast Meeting of the American Institute of Electrical Engineers, Spokane, Wash., September 11, 1914.

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ECONOMY IN THE OPERATION OF 55,000-VOLT INSULATORS

BY M. T. CRAWFORD

ABSTRACT OF PAPER

The author gives a brief outline of the operating experiences on three 55,000-volt lines, two of which have been in service 10 years and one 5 years. The quality of the more modern porcelain insulators is notably superior to those first installed on these lines. A device is described by means of which defective insulators can be readily detected in the very early stages of deterioration, and by periodic use of this device and replacement of insulators, failures in service have been practically eliminated.

THE final measure of success in a transmission system is the cost of securing the desired performance therefrom. The failure of line insulators from breakage or electrical causes is a menace to service performance, and may be the cause of heavy maintenance expense if the failures are frequent and repairs must be made under emergency conditions.

The problem of securing satisfactory and economical operation from lines having gradually weakening insulators, has recently become an important one on some systems.

This paper outlines briefly the operating experience on several of the older lines of the Puget Sound Traction, Light and Power Company system, and describes methods employed to secure satisfactory performance economically.

GENERAL DATA

Nominal voltage, 55,000; non-grounded neutral; 60-cycle, three-phase current. All pin type insulators are of the design shown in Fig. 1.

Line A. In service 10 years, from Electron generating station to Tacoma. Length, 31 miles (49.8 km.). Number of insulators, 4450. Poles, 40-ft. (12-m.), set on average spans of 125 ft. (38 m.). Wires spaced six ft. (1.8 m.). No. 4/0 B. & S. copper 21 miles (33.7 km.); No. 0 B. & S. copper 10 miles (16 km.). Insulators cemented on iron pins. Wooden pins screwed in insulators were used on a portion of this line when first installed, but have nearly all been replaced at this date with iron pins.

Line B. In service 10 years; from Electron generating station to Seattle. Length 47 miles (75.6 km.). Number of insulators 6850. Poles 40 ft. (12-m.), set on average spans of 125 ft. (38 m.). Wires spaced six ft. (1.8 m.). No. 4/0 B. & S. copper. Insulators cemented on iron pins.

Line C. In service five years at 55,000 volts; from Snoqualmie generating stations to Everett, Seattle and Tacoma. Length 160 miles (257.4 km.). Number of insulators 17,350, 4550 of which were in service at 30,000 volts for two years previous to the 55,000-volt service. Poles 35- to 55-ft. (10.6- to 16.7-m.), set on spans from 130 to 300 ft. (39.6 to 91.4 m.). Wires spaced seven and nine ft. (2.1 and 2.7 m.), and vary in size from No. 4 B. & S. copper to No. 4/0 B. & S. aluminum. Insulators screwed on iron pins.

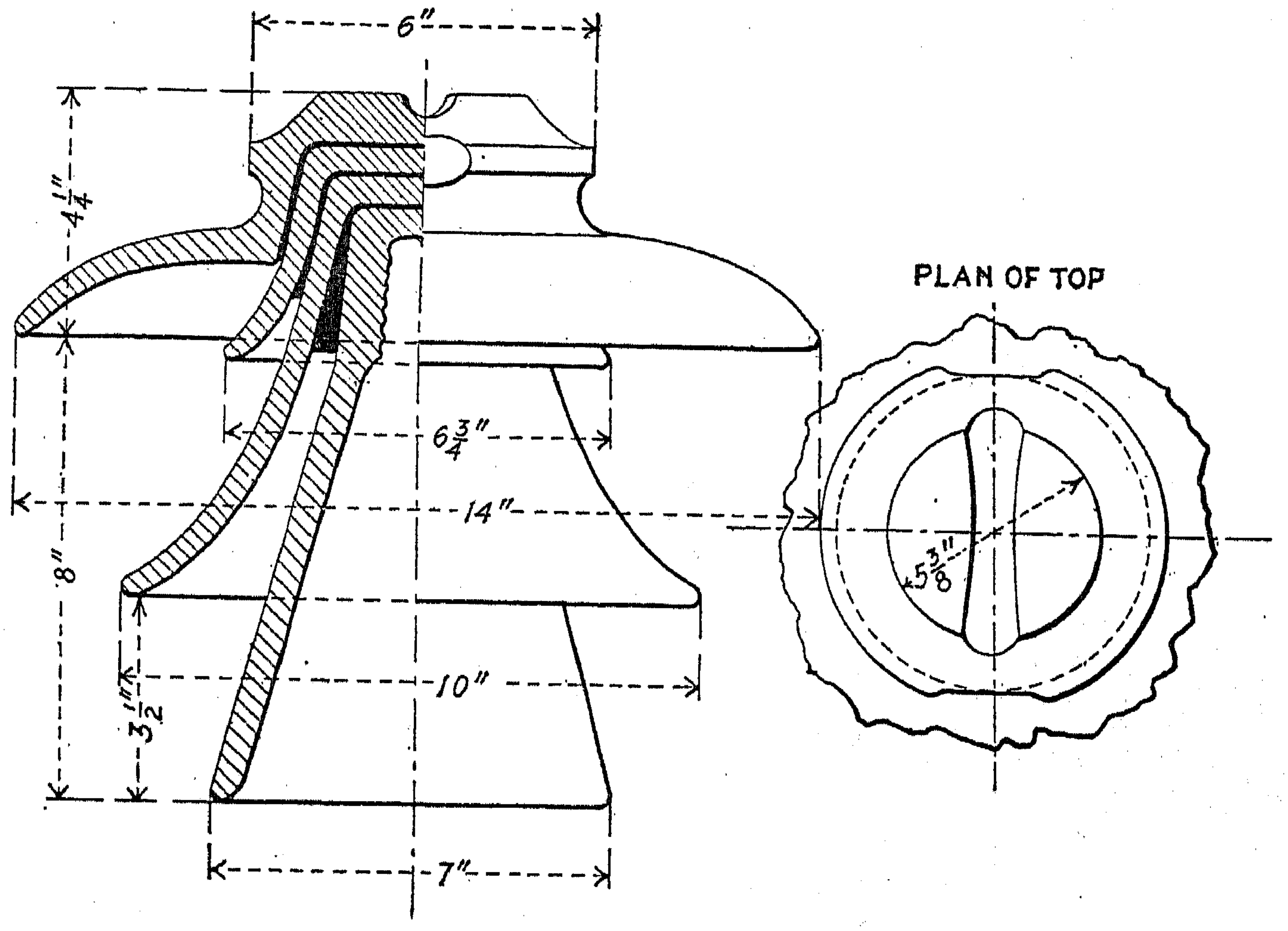


FIG. 1—INSULATOR FOR 60,000-VOLT CONSTRUCTION.

OPERATING HISTORY

Line A. The insulators originally installed on Line A were among the first of their kind and voltage to be made, and the art of high-voltage porcelain manufacture was not well understood at that date. Their appearance indicates that the clay was worked quite dry and that probably the mixture contained a much lower percentage of china clay than is now used. Many samples show a lack of homogeneity in the ware and irregularities of surface, and firing cracks are visible under the glaze. The shells were given a moderate test at the factory and shipped to Tacoma, where they were cemented together and the assembled insulators subjected to a dry test of 120,000 volts. Difficulties with the testing equipment made it necessary to put a portion of the insulators on the line without test. There were failures from time to time during the test, but as it was considered unusually severe, trouble was not anticipated.

Electrical failures began to occur within a short time after installation, especially during line surges and in wet weather, and have continued from time to time to date. The larger shells crack radially and leakage over the smaller shells burns off crossarms. These cracks stand open perceptibly, indicating that there were shrinkage strains in the ware.

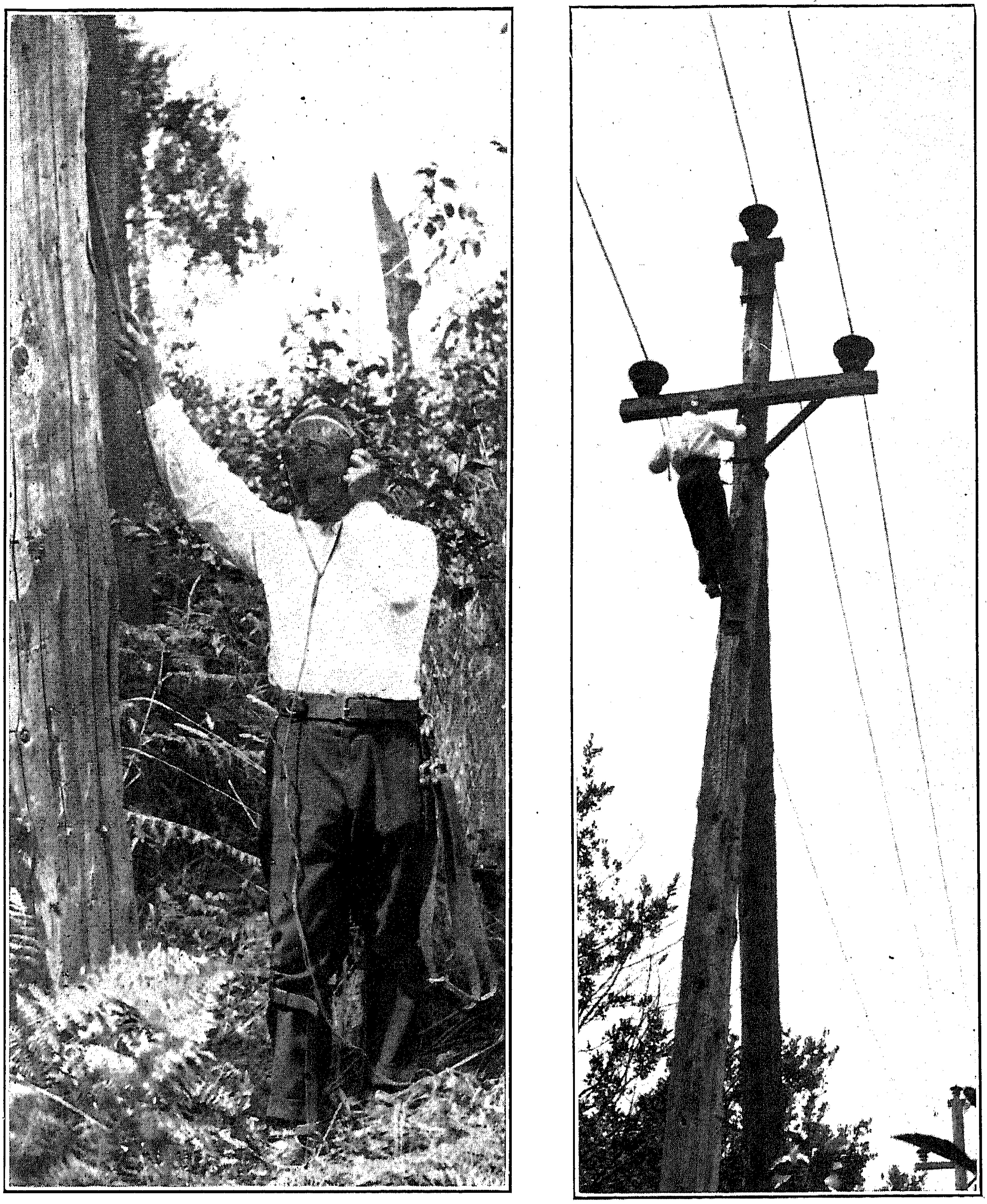
It has been necessary gradually to replace these insulators, until at this date 83 per cent of the original installation has been replaced.

Line B. The insulators on this line were purchased and installed under the same conditions as Line A, but were made at a different factory. The appearance of these insulators indicates a much better grade of porcelain with a smoother surface, but some samples of them do not compare with the ware turned out of the factories today. Such of them as were tested showed a very small percentage of failures. For the first five years of operation, very little trouble was experienced with these insulators, but later on they began breaking down occasionally and recently they have given a good deal of trouble, failing several at a time during an arcing ground at another point on the system. A large number of these insulators were put on Line A to replace failures of the original insulators thereon, so that the total installation of the ware purchased for Line B is about 8200 insulators. Of these, the failures to date have totaled about 4 per cent, nearly half of which have been in the last year. These insulators do not usually have a large radial crack, but a small crack starts on the head or in the side groove and runs around on the top of the insulator. It seems that these cracks enlarge until a leakage current starts through the top two or three shells and discharges over the surface of the lower shell. The tendency of a brush discharge to pass in the positive direction more than the negative, has a rectifying effect on the leakage current. This results in a partly unidirectional current from the bottom shell to the pin, and signs of electrolytic corrosion of the pin head in the cement have frequently been found. Once started, this will soon crack the entire insulator, as the high tensile stress put on the porcelain by this internal expansion will lower its dielectric strength. In many cases insulators have been found which were leaking noisily, and when the line was killed and an examination made, the insulator was found intact, although a number of cracks were visible. As soon as the tie wire was removed, however, the entire insulator fell apart.

Line C. The insulators on this line were made at several different factories and are of as fine a grade of porcelain as can be obtained today. A representative of the company at the factory tested each shell separately, and the assembled insulator, to 120,000 volts for five minutes. Every insulator was given this test and examined for physical defects, and stamped by the inspector if accepted. To date there have been only three failures, and it is possible that these were partially broken in some other way before failure.

A large number of insulators have been installed on pole lines and steel tower lines built within the last few years on this system, which were tested as in Line C and screwed on iron pins, and there have been no failures. About 120 strain insulators, each consisting of three 10-in. (25.4-cm.) diameter link type disks with no cemented parts, have been in service at strain points for three years without trouble.

The expense of replacing outright all the Line B insulators was prohibitive, and they formerly were replaced one by one when they got to the point where the leakage currents could be heard from the ground. This was not entirely satisfactory, however, as they were at an advanced stage of the deterioration before this condition was reached, and frequently failed, causing an arcing ground that punctured other insulators, and a heavy charge against maintenance resulted on account of the emergency nature of the repair work. The first method tried was by using a megger, but no satisfactory results could be obtained unless the testing wire was over the leaking crack and this crack extended clear through to the pin. Each insulator had to be untied and the testing work was very expensive and laborious. After considerable experimenting a device was perfected to locate these insulators at an early stage of the



[CRAWFORD]

FIG. 2—SHOWING METHOD OF USING DEFECTIVE-INSULATOR DETECTING SET

Hand pick consists of insulated tube with sharp pointed steel terminal on one end which is thrust into the pole or crossarm. A sharp steel pin forms the other terminal, which is driven into the ground or pole under the cross arm. A fuse and short-circuiting jack with plug on the receiver set may be inserted in the circuit if there is any probability of a considerable voltage to ground.

depreciating process, so that the work of replacing them could be done economically and before they broke down and damaged other insulators and interrupted service. This device is shown in Fig. 2 and consists of a pair of 2000-ohm wireless telegraph receivers, fitted up for the convenience and safety of the inspector in testing. The hand pick is driven into the pole about seven feet from the ground, and the sharpened pin driven into the ground several feet away. The receiver set is connected between these two, and if all insulators are sound there is a clear audible hum of the same tone as the telephone line, due to the shunting of a part of the capacity current of the insulators on the pole top. If, however, one of them is leaking, a scratching noise is superimposed on the hum, which comes and goes as the neutral shifts to and from the wire on the defective insulator. The inspector then proceeds up the pole and tests between each insulator pin and the center of the crossarm, and thus locates the defective one. This device can be used in a similar manner on steel tower lines. Insulators can be found in this way which have only a very small crack started and which will not puncture on the test below 100,000 volts. Insulators with a crack clear around the head were taken off and tested, puncturing at from 60,000 to 65,000 volts, but no sound was audible from them while on the line without the use of the detecting set. One or two lower petticoats were usually found intact, the leakage current passing over their surface during the test until the puncture point was reached.

Field books are kept with the record of the last test, and data on each insulator on every pole in Lines A and B. With practise the inspector can single out defective insulators which are at an early stage of the depreciating process. These tests can be made while the lines are in service, at very slight additional cost to the routine patrolling. Several hundred insulators can then be replaced at a convenient time and the work organized so as to be done economically. By keeping at this work at regular intervals, failures in service can be practically eliminated.

It seems probable from the history of operation that the porcelain on Lines A and B was of lower dielectric strength originally than that on Line C, and that many of these insulators were therefore under an electric stress which was a large percentage of their ultimate strength. Under these conditions the poorer insulators soon failed, and the better ones gradually weakened, to fail later. The best insulators, however, as on Line C, are being operated at a potential which is a small percentage of their ultimate strength and are showing no signs whatever of weakening or fatigue, although they have only been in service five years. The Line A and Line B insulators began to weaken in less time than this, and it seems that if any process of fatigue were under way, some signs of it would surely be in evidence among 17,350 insulators after five years' service. Although the evidence is not conclusive, it seems probable to the writer that electrical fatigue of porcelain only occurs where the ware is operated under electrical or mechanical or combined stresses which are too close to its ultimate strength Insulators should be designed and individually tested to withstand at least 2¼ times line voltage; and care should be taken that at high potentials, where unit insulators are in series, line voltage is taken as the actual portion of the total voltage which comes on each particular insulator in the string. Where the gradient is not uniform and potential is concentrated more on some units than on others, these units should be designed accordingly and tested as above.

The use of cemented-in metal parts should be avoided in connection with porcelain insulators, thus eliminating any possible trouble due to electrolytic corrosion if leakage currents occur, or due to expansion and contraction strains of the different substances. The use of screwed-on pin-type insulators decreases the cost of replacing, and while not quite as suitable for heavy side strains, the use of strain insulators is better practise for such points.

DISCUSSION ON "ECONOMY IN THE OPERATION OF 55,000-VOLT INSULATORS" (CRAWFORD), SPOKANE, WASH., SEPTEMBER 11, 1914.

J. Harisberger: What brought about the development of testing insulators as mentioned in the paper, was a severe storm in the Puget Sound district last winter, causing a number of breaks in our transmission line where it goes through heavily timbered country, these breaks causing arcing grounds and breaking down insulators all over the system. We had been very proud of our record of uninterrupted service, and this trouble set me to thinking about aging of porcelain that has been so much discussed recently. I have been unwilling to admit to myself that there is such a thing as the aging of porcelain, and I do not believe it now. Last spring I made a trip down the Coast to visit operating companies that have been operating lines of 50,000 volts or over for some time, to get what information I could as to their experience. I visited eight companies and found but one man who was positive that porcelain deteriorated and gradually lost its dielectric strength. I found that the experiences of most of the companies visited were quite similar to our own. The porcelain of some of the insulators in service five to six years, on close examination, showed a mottled surface similar to that of Dedham china ware. On breaking the insulator, discoloration of the cracks to a depth of one-quarter of an inch was occasionally found. There is no doubt that this condition cuts down the insulating quality of the porcelain and these insulators should be weeded out before they are broken down by some disturbance on the system. During my absence, Mr. Crawford developed the method as outlined in this paper for locating such insulators. I believe that everyone having had experience in the operating of high-voltage transmission lines will agree with me that high-frequency disturbances such as are caused by arcing grounds, etc., are most to be dreaded. While in California, I spent half a day with Professor Ryan, of Stanford University, who showed me a practical demonstration as to what high-frequency currents will do. An insulator that would show practically no distress at 150,000 volts at 60 cycles, would be punctured in a few seconds when subjected to over 100,000 cycles and not over 25,000 volts.

It is quite noticeable on our system that the majority of failures are insulators cemented to iron pins. Over seven years ago I objected to cementing insulators to pins and designed a pin with a flexible top for screwing on 60,000-volt insulators. I was much criticised and was told that I would get into trouble on account of the metal expanding and breaking the insulator. We have some 20,000 insulators in service of this type of construction, and I have yet to hear of a failure on account of this type of pin.

M. H. Gerry, Jr.: The design of high-tension line insulators is now pretty well understood, but, of course, it is still a question of effective material and proper distribution. The most important of all is the distribution of electrical stress. This has been discussed many times in the Institute PROCEEDINGS.

V. H. Greisser: The principal thing in this paper of interest to me is the fact that the telephones can be used for delicate practical tests, and we are very fortunate indeed to be able to secure some such instrument that is sensitive enough to test insulators. Practically the only instrument of any use on high-tension work previous to this, has been the oscillograph, and that has not been sensitive enough to be very useful in testing porcelain insulators.

A. A. Miller: I take it for granted that Mr. Greisser's last remark that the oscillograph does not afford the proper means of testing insulators referred to the work which Dr. Ryan has been performing in California, where he has used very high frequencies, away beyond the natural periodicity of the oscillograph, and found that it was very easy to puncture porcelain insulators by using such frequencies. He has a laboratory in which he very effectively demonstrates the ease with which porcelain is punctured by means of these very high frequencies, boring holes right through an insulator. Professor Ryan's investigations I think will throw a great deal of light on that.

H. R. Noack: There has been a great deal of discussion upon the subject of aging of porcelain. I think there is some misconception of the meaning of the term "aging." As I understand it, aging applies particularly to a molecular change in the porcelain itself. Porcelain is a very inert matter and, so far as any studies which I have been able to make on the subject are concerned, there has never been noticed any molecular change within the porcelain itself. The effects commonly considered as aging, I am satisfied, have nothing to do with molecular changes, but are generally due to external influences. For example: porcelain insulators as used today are generally in combination with other materials, such as cement and steel or iron, and some of the changes noted under operating conditions undoubtedly are due more to the influences of a combination of these different materials with different characteristics than to any inherent change in the porcelain itself. Again, there is no known standard, to my knowledge, as to what constitutes perfect or ideal porcelain; different manufacturers have different standards in mixing, firing and in manufacturing, generally, so that there is no one standard which has yet been established as to what constitutes ideal porcelain. Many of the troubles which have been noticed may, in my opinion, be ascribed to improper firing of the porcelain, assuming, of course, that in the first instance the mixture was suitable to make perfect porcelain if handled properly in the subsequent manufacturing operations. It seems to me that, eventually, engineers will have to determine upon some standard for measuring perfect porcelain. An under-fired piece of porcelain is, to a certain degree, porous. The porcelain is almost invariably covered by a glaze, which is a glassy structure and protects the body of the porcelain from external influences, such as moisture and gases, but under operating conditions the glaze may be eventually injured, and even though it is not injured, there are some portions of the porcelain which are not covered by the glaze, due to manufacturing necessities, so that gradually there may be absorption of moisture, which, when subjected to heating influences due to electric currents, may cause expansion to such a degree as to gradually develop minute cracks, and these, though microscopic at first, will eventually grow in intensity, and finally allow the porcelain to puncture. On the other hand, the porcelain is sometimes over-fired, in which case it takes on a glassy structure and is not capable of resisting the influences of alternate expansion and contraction to the same degree as perfect porcelain.

The question of "aging" is one of great importance and, as I said in the beginning of my remarks, I do not believe that it has been demonstrated that any such phenomenon exists, but that the difficulties arising from so-called "aging" are due to external influences.

T. R. Cornick: I was with the Mexican Light & Power Company when its line was first put into operation. We had approximately 500 miles of 60,000-volt circuit and later 40 or 50 miles of 20,000-volt circuit. I was there for approximately five years after these lines went into operation and I do not think that I ever discovered any "aging." We did have a lot of trouble due to electrical disturbances and I should say approximately twenty punctures. Those punctures took place, however, when these electrical disturbances were on; therefore we did not call them the "aging" of the insulator. That line after being in operation at 60,000 volts for several years was increased to 80,000. The insulators of course were changed. To start with we used the Rio type, 14 1/2 in., which was changed to, I think, 18 in. when they went to 80,000 volts. Since they went to 80,000 volts they have had no appreciable increase of trouble. Our troubles all took place before we put on the ground-wire. After we put on the ground-wire our troubles decreased, from, you might say, every day of the rainy season (during six months of the year) to approximately three cases of trouble during the rainy season. We, therefore, took it that the trouble was purely and simply the lightning and not trouble with the insulators. Therefore, I think Mr. Noack is right in his discussion in that it isn't a case of "aging" of the insulators but is doubtless a case of poor mixing, or poor manufacture.

P. M. Lincoln: I ask Mr. Cornick if the ground wire was overhead?

T. R. Cornick: Yes, overhead ground wire.

L. T. Merwin: I can't offer anything from experience here in Washington, because the line of the company with which I am connected has been in operation only 17 months. I might say, however, the insulators that are now being put on the market are certainly remarkable for the factor of safety that is offered. I speak now from the experience of an instance on our line shortly after it was put into operation. It was on June 17th of last year, when we had a turbine runaway in our plant. After we had patched things up, and got the line in operating condition again, or rather got the plant in operating condition again, we tried to repeat the runaway under hand control, and one of the results that we obtained by interpolation and extension of the graphic lines on our charts showed that we must have had, during that runaway, an impressed voltage on the line of something between 150,000 and 200,000 volts. The line is of wooden-pole construction with steel-core aluminum conductors and pin type insulators, with four strain units in a dead end. The pin type insulators had cemented lead thimbles in the top of the insulators, the lead thimbles receiving a ¾-in. steel pin. Now, since that runaway and the impressing of that extremely high voltage on our line we have not had a single breakdown, neither did we have a single breakdown up to that time. The line was put in operation on the 25th of April, 1913, and on June 17th the runaway occurred with this high impressed voltage. It is now approximately fifteen months, and we have yet to experience our first insulator failure.

I might also add that on another occasion our insulators withstood a severe arcing ground for 1¾ hours before the faulty section could be cut out by open air switching. This occurred quite recently, with no bad results.

Incidentally, our lines are delta-star connected with ungrounded neutral, and I was able to carry load through this very severe arc. Now it is, I should say, a remarkable thing that insulators have such a large factor of safety as to stand a voltage of two to three times the working voltage. The farmers along our line described the spectacle as being awe-inspiring. Of course any high arc is awe-inspiring to the layman; but from reports our line must have been lit up with corona from one end to the other and apparently looked like a solid streak of fire from the White Salmon river clear through to Camas. So if there is any aging in insulators it certainly has not appeared yet in the seventeen months of operation, and there certainly were no immediate bad results.

L. J. Corbett: There is one point that I would bring up here which has not been touched upon as yet, and that is the matter of glass insulators and their possibilities. We have heard thus far only regarding the changes in the porcelain insulators. The porcelain manufacturers have been busy for some time and have been doing very effective work, and they appear to have a very reliable product at the present time. It seems to me that glass, with its superior insulating qualities, should be worked upon a little more by the glass manufacturers and it may be possible that a more effective insulator, an insulator more constant in its qualities, could be developed. The objection I believe is the uncertainty of glass in its mechanical strength. The difficulty about the porcelain is the uncertainty in its electrical strength, and I would like to see in the future more development in that line if there are actual possibilities.

Ralph W. Pope: I have been thinking of glass during this discussion. Mr. Field, who was one of the early electrical engineers in California, stated that the possibilities of glass for long-distance transmission insulation had been overlooked; and I may say, in reply to Mr. Corbett, that the manufacturers have gone into this question very thoroughly, and some of the data as regards tests will be found in the TRANSACTIONS, 1912, XXXI, p. 2195. If there is any doubt as to the relative qualities of porcelain and glass it would be wise to put them in operation at the same time and study the results simultaneously so that if there is a possibility of the glass insulator being better it could be ascertained in that way. In the discussion which took place at the Cooperstown convention on insulators the question of mixing of porcelain came up for consideration, and it appears to have been maintained that it wasn't the business of the electrical engineer to go into the mixing of porcelain, but that that was the work of the ceramic engineer. There is no doubt but that the manufacturers of porcelain insulators are investigating this; but, as it appears to me, it is a rather difficult matter, and the committee found it so, to arrive at a standard of perfect porcelain. The mechanical stress is a very important feature, and I think that is particularly what the manufacturers had in view in the construction of glass insulators. Those can be obtained now, I believe, in almost any form, and I think it would be worth while for engineers to test out their possibilities.

M. H. Gerry, Jr.: There is considerable misunderstanding on the subject of glass insulators. Glass is weaker mechanically than porcelain, and is also subject to internal strains, which may cause cracking when exposed to varying temperatures. The internal strains can be obviated to a considerable extent by proper design and can be materially reduced by careful annealing during manufacture. Glass insulators in many instances will give most excellent results; they are always cheaper and often better than porcelain insulators. I have had personal experience with over 200,000 glass insulators under operating conditions at voltages from 25,000 to 70,000, and I have never known an electrical failure traceable directly to the material. Where trouble has occurred, it has been due either to defective design, improper annealing or too great mechanical strain on the insulator. It would be impossible to make a statement of this kind for porcelain, as a great many electrical failures have been due to defective material.

A. A. Miller: I ask Mr. Gerry whether or not he considers the new form of insulators, in which there are disks placed in series to each other, contributes in any way to the elimination of these internal strains. In other words, the disks, it seems to me, would contribute to the elimination of these internal strains a great deal more than the petticoat insulators.

M. H. Gerry, Jr.: It is entirely a question of proper annealing of the glass during manufacture and the relative proportions of the different parts of the insulator.

E. Woodbury: I ask Mr. Harisberger if he can tell how they would apply this test of the telephone receiver in case of a tower line or a wooden structure having pins grounded.

He also mentioned that probably it was bad practise to have cemented pins in the insulators; in view of this, do they use insulators with cemented-in metal thimbles, or are the insulators screwed directly onto the pins?

He also mentioned link-type strain insulators. It is my understanding that that type is not now manufactured, and that all suspension type insulators, therefore, would have cement. In line with his remarks on insulator troubles, we have been in the habit of shutting down at convenient times our lines having pin-type insulators, and tapping the insulators with a stick to determine the cracked ones. On the coast where we had considerable trouble with burning off of poles and cross-arms on a 15,000-volt line, we have connected the iron pins together with a wire and have stopped absolutely all the burning of poles.

J. Harisberger: I have not had any experience with glass insulators for high-voltage lines, but if anyone is qualified to speak on that subject, Mr. Gerry is.

We have had no occasion for locating faulty insulators on tower lines, as we have only some 12 miles of tower line and the insulators have only been in service a little over two years and have given absolutely no trouble.

In answer to Mr. Woodbury's question, I will say that insulators cemented to iron pins have a threaded $1\frac{3}{8}$-in. pin hole. Whenever an insulator is broken, we do not change the pin, but place a threaded sleeve of soft metal over the top of pin and screw on a new insulator. This sleeve was designed for this purpose and costs about two cents.

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REPORT
by the
JOINT COMMITTEE ON INDUCTIVE INTERFERENCE
to the
RAILROAD COMMISSION OF THE STATE OF CALIFORNIA

SCOPE

THIS report presents briefly an account of the formation of this Committee, its activities and results accomplished to date, and recommendations for such rulings by the Railroad Commission of the State of California as the Committee believes are justified at this time; together with a technical discussion in explanation of the results and recommendations.

HISTORICAL

The formation of the Joint Committee on Inductive Interference was the outgrowth of certain differences involving power, communication and railroad interests which were brought to the attention of the Railroad Commission of California. As an alternative to contesting the issue at that time it was agreed by the power and communication companies, with the approval of the Commission, that a joint investigation should be made to obtain certain information essential to a proper solution of the difficulties. The Commission desired that the matter be thoroughly investigated before passing upon the general principles involved in these difficulties. To this end a general conference was called to select representatives to form a "Joint Committee" empowered to conduct tests, experiments and investigations, the results of which would serve as a basis of recommendations for rules and regulations, to be issued by the

Commission, tending to minimize inductive interference and physical hazard arising from parallelism of different classes of circuits. This conference was held December 16, 1912. As a result, the Joint Committee on Inductive Interference, representing the Railroad Commission and railroad, power, and communication interests of the State, was organized and authorized by the Railroad Commission of California to conduct the desired investigation.

The organization and personnel of the Joint Committee on Inductive Interference were approved by the Railroad Commission on January 6, 1913, and the Committee thereupon proceeded with the necessary tests and investigations.

For the more efficient conduct of its work the Joint Committee was divided into several smaller sub-committees, each assigned to, and responsible for, certain branches of the investigation. The present organization of the Joint Committee is given on a chart presented as Appendix VI.

Early in its work the Joint Committee established a field engineering staff reporting to the Sub-committee on Tests, to conduct the necessary tests and investigations. This field staff was composed of engineers in the employ of The Pacific Telephone and Telegraph Company and the American Telephone and Telegraph Company and was later augmented by the addition of two engineers and a stenographer engaged by the Joint Committee.

Previous to the formation of this Committee in December 1912, The Pacific Telephone and Telegraph Company had started an investigation of inductive interference between the lines of the Coast Counties Gas and Electric Company and the lines of the telephone company in the neighborhood of Morganhill in Santa Clara County. This investigation was completed by the Joint Committee and its results have been considered in connection with other work carried out by the Joint Committee.

In January, 1913, the Joint Committee established its field staff at Salinas, to investigate parallels on the lines of the Sierra and San Francisco Power Company north of Salinas and on the lines of the Coast Valleys Gas and Electric Company south of Salinas, both of these power lines being parallel with lines of The Pacific Telephone and Telegraph Company, the Western Union Telegraph Company and the Southern Pacific Company's signaling system. The investigation at Salinas continued from January 1913 until July 1913.

The specific work undertaken at Salinas was: a determination of the magnitude and characteristics of the induction produced in the communication circuits, the factors in the power circuits causing this induction, the quantitative relationship of cause and effect, and a comparison of the effects on the parallels north of Salinas with the neutral of the power circuit alternatively grounded beyond one end of the parallel and beyond both ends of the parallel.

In July 1913 the field headquarters were moved to Santa Cruz. At this point the Committee desired to test the relative merits of various schemes of transposition for both power and telephone circuits, and to complete the investigation begun at Morganhill on the system of the Coast Counties Gas and Electric Company, which system is of a different character from that studied at Salinas. A mathematical study of transpositions in general, and particularly of those for the parallel between Santa Cruz and Watsonville, has been completed. The experimental study of these schemes of transpositions has not as yet been completed.

Owing to the peculiar nature of the experimental work and the refinements required, suitable apparatus was not easily obtainable and in many instances it was necessary to design and develop special apparatus for certain of the tests. A considerable amount of time has necessarily been spent at all points of the tests in choosing, from the almost innumerable things which could be investigated with profit, those of greatest value which could be carried out with the means at hand.

In the course of its investigations the Committee has prepared a series of fifty technical reports which present and discuss in detail the various features of the work, the methods and apparatus employed and the results accomplished. These reports, which are on file at the Committee headquarters in the offices of the Railroad Commission of California, are listed in Appendix V.

RESULTS ACCOMPLISHED

The following paragraphs summarize very briefly the principal results accomplished to date. These statements of results are accompanied by brief explanatory comment upon the conclusions reached. The reasons for and explanations of these conclusions are given in more detail in the appendices to which reference is made.

1. *Interference to telephone circuits under normal operating conditions of power circuits arises almost wholly from the harmonic voltages and currents of the power systems. (See Appendix I).*

This is due chiefly to the fact that the frequencies of the harmonics generally present in the voltages and currents of power systems cover a considerable portion of the range of the voice frequencies, particularly those frequencies at which telephone instruments and the human ear are of maximum sensibility. Extraneous currents of frequencies approaching the average voice frequency have a more injurious effect upon telephone conversation than currents of lower frequencies.

2. *The effect of induction of the fundamental frequency on telephone circuits is comparatively unimportant unless it is of magnitude sufficient to constitute a physical hazard. (See Appendix I).*

This is due to the fact that the fundamental approaches the lower limit of audible frequencies, at which the telephone and the human ear are not efficiently responsive.

3. *Interference to telegraph and other signaling circuits is due principally to the fundamental and lower harmonics. (See Appendix I).*

Telegraph receiving instruments are relatively insensitive, as compared with the telephone, to the higher harmonics, but are sensitive to disturbances of lower frequencies, such as the fundamental and lower harmonics which more nearly approach the normal operating frequency of such circuits.

4. *The power circuit currents and voltages may be divided into two factors: balanced and residual, of which, for equal magnitudes, the latter in general produce the greater inductive interference. (See Appendix II).*

Residual currents and voltages act inductively in a similar manner to single-phase currents and voltages acting in a circuit composed of the line conductors in parallel with earth return, which is a condition favorable to very large induction. Moreover, such a circuit which includes the earth as one side cannot be transposed. Transpositions in the power circuit cannot reduce the inductive effect of residuals except as they reduce the magnitudes of the residuals themselves, which they do in some cases. The inductive interference arising from such currents and voltages can be reduced only in the case of metallic circuits such as telephone circuits, by transposing these circuits. It is therefore important that the telephone circuits be transposed at frequent intervals throughout parallels and carefully balanced throughout their entire length and that the residual currents and voltages be kept sufficiently small to give negligible induction in telephone circuits so arranged.

5. *Inductive interference to communication circuits, arising from the balanced voltages and currents, can in a large measure be prevented by means of an adequate system of transpositions applied to both power and communication circuits (assuming the latter are metallic) and located with due regard to each other.*

This is accomplished partly by creating mutually neutralizing inductive effects in neighboring lengths of each side of the communication circuit or circuits by transposing the power circuit, and partly by equalizing the inductive effects on the two sides of the communication circuit or circuits by exposing each side equally to the influence of the power circuit by transposing the communication circuit.

6. *Abnormal conditions and at times switching operations produce transient disturbances of a very severe character.*

This is due to the fact that abnormal conditions almost invariably give rise to residuals of large magnitude, often including high harmonics. Abnormal occurrences incident to electrical power transmission do not give warning of their occurrence, and since they cannot be produced artificially on transmission systems without subjecting the apparatus to great risk or danger, it has been deemed unwise to attempt any experimental tests of these effects. This conclusion is therefore drawn from general experience and data of actual occurrences collected by the Committee.

RULES RECOMMENDED BY THE COMMITTEE

The following are the rules which the Committee, as the result of its study to date, recommends be issued at this time to govern the future construction and operation of power and communication circuits which are or are proposed to be so located as to create a parallel as hereinafter defined.

OUTLINE OF RULES

Definitions.

a. Power Circuit
b. Communication Circuit
c. Telephone Circuit
d. Line.
e. Parallel or Parallelism

- f. Residual Current
- g. Residual Voltage
- h. Transposition.

I. Avoidance of Parallelism

II. Conditions under which Parallelism will be Permitted.

- a. Minimum Horizontal Separation
- b. Balance of Power System
- c. Limitation of Residual Currents and Voltages
- d. Transpositions Inside Limits of Parallel
- e. Transpositions Outside Limits of Parallel
- f. Uniformity of Parallel
- g. Transformer Connections
- h. Switch Equipment
- i. Switching
- j. Use of Air Switches
- k. Abnormal Conditions
- l. Devices for Indicating Abnormal Conditions on Systems Isolated from Ground.
- m. Procedure under Abnormal Conditions
- n. Ammeters in Neutral Ground Connections
- o. Charging Electrolytic Lightning Arresters
- p. Wave Form of Rotating Machines
- q. Exciting Current of Transformers.

III. Provisions Applying to Existing Parallels

IV. Waiver of Conditions by Communication Company

V. Parallelism with Alternating-Current Railways.

Definitions

The following definitions are given of certain technical terms employed herein:

a. *Power Circuit.* The term " power circuit" includes any overhead constant-potential alternating-current power transmission or distribution circuit or electrically connected network which has a voltage of five thousand volts or more between any two conductors or of three thousand volts or more between any conductor and ground.

b. *Communication Circuit.* The term " communication circuit " includes any overhead, open wire telephone, telegraph, or signaling circuit which is used in the service of the public.

c. *Telephone Circuit.* The term " telephone circuit " includes any inter-exchange metallic telephone circuit, and therefore excludes subscriber's circuits. This term also includes any metallic telephone circuit operated by any railroad or other company for dispatching purposes or for public use between separate communities.

d. *Line.* The term " line " means any circuit or aggregation of circuits carried on poles or towers.

e. *Parallel or Parallelism.* The terms " parallel " or " parallelism " refer to cases where a power line and a communication line follow substantially the same course, or are otherwise in proximity for a sufficient distance, so that the power circuit is liable to create inductive interference in the communication circuits.

f. *Residual Current.* The term "residual current" denotes the vector sum of the currents in the several conductors of a power circuit.

g. *Residual Voltage.* The term "residual voltage" denotes the vector sum of the voltages to ground of the several conductors of a power circuit.

h. *Transposition.* The term "transposition" denotes the interchange of position of the several conductors of a circuit.

I. Avoidance of Parallelism

Every reasonable effort shall be made to avoid new parallelism. The party proposing to build a new communication or power line, which will create a parallel, or generally to reconstruct an existing line involved in a parallel shall give due notice (at least thirty days wherever possible) of its intention to the other party, including detailed information as to the location and character of the proposed line. If a plan can be devised and agreed upon by the two parties for maintaining an adequate separation between the two classes of lines so as to avoid interference, this shall be done. In case it is impracticable to secure adequate separation between a power line and a communication line, parallelism will be permitted subject to the conditions set forth in II.

II. Conditions under which Parallelism will be Permitted

a. *Minimum Horizontal Separation.* The minimum horizontal separation between the power line and communication line shall be equal to the height of the taller line. The only exceptions to this provision are angle crossings and other unavoidable cases of close proximity, and in all such cases the power line shall be kept above the communication line and constructed in conformity with the National Electric Light Association's specifications for overhead crossings or other approved equivalent which may be agreed to by both companies.

b. *Balance of Power System.* The power company shall exercise due diligence to keep the currents in, and the voltages to ground of, the conductors of any power circuit involved in a parallel, as closely balanced as practicable. In all cases where telephone circuits are involved, special consideration shall be given to the prevention or elimination of harmonics in the residual current and in the residual voltage.

c. *Limitation of Residual Currents and Voltages.* Pending additional rules on specific means other than those given herein, the parties concerned shall endeavor to agree upon the means to be employed for the prevention or limitation of residual currents and voltages, and in the event of disagreement the matter shall be referred to the Railroad Commission of the State of California.

d. *Transpositions Inside Limits of Parallel.* An adequate system of transpositions shall be installed in the power circuit (or circuits), and in the communication circuit (or circuits) provided the latter is metallic. When both circuits are transposed the transpositions in both the communication and power circuits shall be located with due regard to each other.

Every reasonable effort shall be made by both parties concerned to fix the limits of the parallel and the location of crossings, branch lines, and connected apparatus so as to facilitate the application of an effective transposition scheme.

In the case of a parallel between a power line and a telephone line the company owning or operating the telephone line involved shall have the right to specify the number, type (in respect to electrical characteristics) and location of the transpositions in the power circuit, subject to the following limitations:

1. For power circuits of 50,000 volts or over, the average distance between successive transpositions shall not be required to be less than one mile and the minimum distance between any two successive transpositions shall not be required to be less than two-thirds of a mile.
2. For power circuits of less than 50,000 volts the distance between successive transpositions shall not be required to be less than one-sixth mile.

The transposition system of the telephone circuits shall be modified where necessary in order that the power and telephone circuits shall be, as nearly as practicable, mutually non-inductive.

For short parallels less than six miles in length (or short sections of longer parallels which have to be treated independently because of abrupt change in conditions) with power circuits of 50,000 volts or over, where it is impracticable to obtain an adequate balance by the location of transpositions in accordance with the limit specified above, the company owning or operating the telephone line involved shall have the right to specify the number, type and location of transpositions provided the distance specified between successive transpositions is not less than one-half mile.

When necessary (due to variations in lengths of telephone transposition sections) in order to secure an adequate balance, a reduction of 10 per cent in the limiting distances between successive power circuit transpositions as given above, shall be allowed.

In the case of a parallel between a power line and a telegraph line or other grounded communication circuit, the location of the transpositions in the power line shall be with due regard to the limits of the parallel in order to form as nearly as practicable a balanced system. The location and type of such transpositions shall be as specified by the communication company, subject to the condition that the transpositions in the power circuit may not be required to be less than one mile apart.

In no case shall the power company be required to relocate poles or towers for the transpositions.

The parties concerned in any proposed parallel shall endeavor to agree upon a transposition scheme for such parallel in accordance with the above. In the event of a disagreement, the matter shall be referred to the Railroad Commission of the State of California.

e. *Transpositions Outside Limits of Parallel.* In addition to transpositions within the limits of a parallel, as provided in "d" hereof, each new power circuit isolated from ground (or extension of such existing circuit) which is constructed subsequent to the date when these rules become effective, shall be transposed throughout its entire length in such manner as to balance the electrostatic capacities to earth of its several conductors, so as to avoid inequalities among the voltages to earth of the several conductors, which would create inductive interference. Such transpositions shall not be more than eight miles apart, provided however, that circuits less than three miles in length are not required to be transposed until they are extended to a greater length; except that extensions or spurs from existing lines, the electrostatic capacities to earth of whose conductors are balanced, shall be so constructed as not to change materially the balance of the existing lines to which they are connected.

f. *Uniformity of Parallel.* To facilitate the application of effective transpositions, both parties shall endeavor to maintain uniform separation, uniform arrangement of conductors and uniform relative location of the two classes of circuits within the limits of a parallel. However, when it is feasible to secure a substantial increase of separation between the two lines for a considerable portion of a parallel, this shall be done, as such an increase of separation is of more benefit than uniformity.

g. *Transformer Connections.* (1) On any power circuit involved in a parallel, no grounded single-phase, or grounded open-star transformer connections shall be employed.

NOTE: This does not apply to railroads operating alternating-current trolleys with ground return, which are covered by V.

(2) On a power circuit involved in a parallel, no star-connected transformers or auto-transformers with grounded neutral shall be employed, unless delta-connected secondary or tertiary windings or other equivalent means are used of suppressing the third harmonic components of the residual voltages and currents introduced by the transformers.

(3) Where single-phase loads are connected to a polyphase power circuit involved in a parallel, the power company shall endeavor to arrange successive connections of this type so as to equalize the loads upon the several phases.

(4) On a three-phase circuit involved in a parallel, the power company shall use, wherever practicable, a closed-delta connection in preference to an open-delta connection, and where the latter is employed an effort shall be made to distribute such connections equally upon the several phases.

h. *Switch Equipment.* A power circuit involved in a parallel shall be equipped, between the source of supply and the parallel, with oil switches, all poles of which shall be mechanically interconnected for simultaneous action. With the exception of stations where an operator is constantly on duty, these switches shall be rendered automatic for short-circuits, grounds, and abnormal neutral currents.

i. *Switching.* All switching on all parts of a system connected to a circuit involved in a parallel, which causes harmful transient disturbances in communication circuits, shall be done by means of oil switches, all poles of which are mechanically interconnected for simultaneous operation.

j. *Use of Air Switches.* The use of air switches, on a power circuit involved in a parallel, is prohibited except for purposes of isolating sections of dead line, or for disconnecting transformers under no load. This applies to the entire power system, any circuit of which is involved in a parallel, unless such switching is so remote as not to cause harmful transient disturbances in the communication circuits.

k. *Abnormal Condition.* A power circuit involved in a parallel shall not be operated at any time with an open, grounded or short-circuited line wire or wires or transformer winding.

l. *Devices for Indicating Abnormal Conditions on Systems Isolated from Ground.* If a power circuit involved in a parallel is electrically isolated from ground, reliable indicating devices shall be installed at its source of supply to inform the operator immediately of abnormal conditions, such as grounds and whereever possible, open circuits, which have not operated automatic switches. Upon indication of trouble by such devices, the operator shall immediately open the oil switches and proceed in the manner outlined in "m".

m. *Procedure under Abnormal Conditions.* In case of the opening of an oil switch due to an abnormal condition in a power circuit involved in a parallel, or any circuit supplying or supplied by the same, such switch may be closed once; if opened a second time due to the continuance of the fault or abnormal condition, said switch shall not be closed again until the line has been sectionalized. The fault may then be located by energizing sections of line, provided that further sectionalization of the line be done in such sequence as to cause the minimum disturbance to parallel communication circuits, and provided further that where practicable the faulty section of line shall be energized but once in this process of sectionalization, where the fault exists within or beyond the parallel, until such fault is remedied.

n. *Ammeters in Neutral Ground Connections.* Wherever a neutral ground connection is employed on a circuit involved in a parallel, an ammeter, suitable for measuring as accurately as practicable the current in the neutral under normal operating conditions, shall be installed in all neutral connections at the main generating and substations on the power system electrically connected to the circuit involved in the parallel. The power company shall maintain a record of hourly measurements of the neutral current at all such points.

o. *Charging Electrolytic Lightning Arresters.* Where a power system is equipped with electrolytic lightning arresters so charged as to cause inductive interference in communication circuits the method of charging the arresters shall be modified to eliminate the disturbances as far as possible. The charging of such lightning arresters shall be done at such time as to give the minimum liability of interference with communication circuit operation, preferably between the hours of 2 A.M. and 4 A.M.

p. *Wave Form of Rotating Machines.* The power company shall make every effort to obtain generators and synchronous motors for use on all parts of the system, giving, as nearly as reasonably possible, pure sine waves of voltage at fundamental frequency. In no case shall the deviation from a pure sine wave exceed the limit set forth in the Standardization Rules of the American Institute of Electrical Engineers.

q. *Exciting Current of Transformers.* In order that the wave shapes of voltage and current may be distorted as little as practicable by transformers, the main line transformers employed on circuits involved in a parallel and on future extensions of such circuits shall have an exciting current as low as is consistent with good practise, and in no case shall the exciting current at rated voltage exceed ten per cent of the full load current. Such transformers shall not be operated at more than ten per cent above their rated voltage.

III. Provisions Applying to Existing Parallels

The following sections of II shall apply also to power circuits involved in existing parallels; b, i, j, k, l, m, n, o, p, and q. Also g-3 and g-4 shall apply to existing parallels to the extent that transformers added hereafter shall be connected as provided in said rules.

IV. Waiver of Conditions by Communication Company

At the option of the company operating the communication circuit or circuits any of the provisions of II and III may be waived.

V. Parallelism with Alternating-Current Railways

It is recognized that railroads operating alternating-current trolleys with ground return create serious inductive interference with parallel communication circuits. In the present state of the art, no means for completely overcoming inductive interference from such parallels is known, hence, they are to be avoided if possible and where unavoidable, the responsibilities arising therefrom must be settled by mutual agreement or in case of inability to agree the matter shall be referred to the Railroad Commission of the State of California.

Discussion of Rules

It will be noted from the definitions that the terms "power circuit" and "telephone circuit" are used in these rules in a special, restricted sense.

(I) The first and most obvious means of preventing inductive interference is to avoid the close association of power and communication circuits. Further, it is recognized that in no other way can complete freedom from interference be secured. While with the ever increasing network of electrical circuits of all inds, adequate separation to avoid interference is becoming icreasingly difficult to maintain, the Committee feels that the nportance of such separation justifies its being made the first remise in rules designed to prevent inductive interference.

Notice, sufficiently in advance, should be given the other arty or parties concerned in any proposed parallel in order iat thorough consideration may be given by both parties to ossible means of avoiding the parallel, or, in case the parallel innot be avoided, to the necessary remedial measures to be nployed.

(II-a) The best insurance against physical hazard in cases close proximity is to maintain a separation equal to the height the taller line, thus avoiding the possibility of physical conict in case of failure. In the case of crossings and unavoidable ises of close proximity for short distances extra-strength conruction is necessary as a precaution against failure.

(II-b-c) As has been pointed out under the heading "Results ccomplished", and more fully explained in Appendix II, sidual voltages and currents are particularly troublesome ctors in causing interference. Means to eliminate or reduce ich residuals in power systems are highly important and while formation at this time does not enable the Committee to formate as explicit a rule as is desirable, yet the importance of the ibject justifies its inclusion in the rules. The acquisition of rther information on which to base a more explicit rule upon iis subject is a most important problem, the experimental udy of which is discussed in the following section of this report.

(II-d) Transpositions properly located in both power and mmunication circuits offer the most reliable and effective eans for preventing interference from balanced voltages and irrents of power circuits. While the inductive effects increase severity for the higher voltage circuits, due in part to the ineased separation of the line conductors, which renders more equent transpositions desirable, the mechanical difficulties volved are so great as to over balance the other reasons and e rules, therefore, provide for less frequent transpositions in e higher voltage circuits than in the lower voltage circuits. further reason for frequent transpositions in the lower voltge circuits is the necessity of a flexible system of transpositions plicable to short parallels which generally occur with such rcuits.

(II-e) The provision requiring transpositions outside the limits of a parallel on systems electrically isolated from ground is an explicit measure for carrying out the purpose of the more general provision given under II-b-c, "Balance of Power System" and "Limitation of Residual Voltages and Currents."

(II-f) Non-uniformity of separation and type of construction within the limts of a parallel are inequalities which cannot in many cases be taken into account in the design and layout of transposition schemes. Such inequalities tend to nullify the effectiveness of the transpositions; hence, it is desirable that they be avoided. A precautionary statement is included in the rule in order that the possibility of securing a wide separation for a considerable portion of a parallel may not be sacrificed for the sake of absolute uniformity throughout the entire length.

(II-g) Some types of transformer connections and methods of operation give rise to large residual voltages and currents and certain provisions of the rules are designed to prohibit or restrict the use of such connections and methods of operation. These rules may be considered as explicit provisions complying with the general provision in II-b-c, "Balance of Power System" and "Limitation of Residual Voltages and Currents". The sufficiency of these specific provisions as an insurance against harmful residual voltages and currents is subject to future determination.

The present information of the Committee does not warrant the definite recommendation of any one type of connection or method of operation as best from the standpoint of inductive interference. This is true as to the relative merits of the two general types of systems, the grounded neutral and the isolated system. The advantages and disadvantages of these general types and any modifications of these types are dependent upon their inherent characteristics in respect to residuals and the limitations and control of residuals under both normal and abnormal conditions. Both types are on an equality with respect to the interference caused by balanced voltages and currents.

(II-k) Continued operation under certain abnormal conditions is possible in some power systems. In particular, it is possible to operate a grounded star-connected system with one phase open, and it is possible to continue the operation of an isolated system when one phase becomes grounded accidentally. The former gives rise to a large residual current and the latter to a large residual voltage, both of which are liable to render parallel communication circuits inoperative. For these reasons the rule prohibits such operation, which, aside from the consideration of inductive interference, does not constitute good practise in power system operation.

(II-h-1-n) To provide that operation under the abnormal conditions mentioned above may not continue without the knowledge of the power company, the rules specify that devices for indicating grounds shall be installed on isolated systems. With respect to grounded star-connected systems, the rules specify with certain exceptions the automatic opening of switches by abnormal neutral currents. In such systems ammeters are required in all main neutral ground connections. Such ammeters, read regularly, afford means of detecting abnormal neutral currents and are of value in showing the degree of balance of the system, as the neutral current is easily affected by unbalanced conditions.

(II-m) Accidental causes give rise to occasional abnormal conditions. These can only be guarded against by good construction and maintenance, and careful operation which, however, cannot prevent entirely such occurrences. When trouble develops on a power circuit involved in a parallel, it is always liable to cause serious interference to the communication circuits, if the exposure is severe. In the present state of the art, the method of fault location on power circuits is a process of repeated sectionalization and energization of the faulty line until the fault is located within certain limits. This process causes repeated interruptions with loss of time in the operation of the communication circuits, and in the case of telephone circuits is accompanied sometimes by injury to the operators. It should be explained that the loss of time is much greater than the duration of the disturbance, owing to the time required to restore the protective devices on the communication circuits to their normal condition. No method of locating faults on power circuits is known which meets the requirements of practise and yet avoids the disadvantages of the present method. The inductive disturbances due to fault location can be to a considerable degree ameliorated by disconnecting the faulty line from the rest of the system and energizing this line by a single generator at such excitation as may be necessary to overcome the insulation of the fault. Whenever practicable this method is employed by power companies; hence, it has not been thought necessary to cover it by a specific rule.

In view of these facts, the Committee is recommending the limitation of the present practice in this regard so as to avoid, as far as seems practicable, the repeated interruptions to communication circuit operation. It is highly desirable that some better method of fault location be developed, not only because of the attendant consequences of the present method on communication circuits, but also because of the abnormal strains to which the power apparatus is necessarily subjected.

(II-h-i-j) Normal switching operations on power circuits produce at times severe transient disturbances in parallel communication circuits. The commonly recognized fact that oil switches produce less severe transient disturbances in power circuits, affords the basis for the provisions in the rules dealing with switches and switching. The automatic features required are designed to prevent continued operation under abnormal conditions.

(II-o) Transient disturbances of severe nature to telephone circuits are sometimes caused by the charging of electrolytic lightning arresters. There are available methods of diminishing the transients due to this cause, and a general provision to the effect that such methods shall be employed when necessary, is included in this rule. It is further provided that the charging of the arresters should be done at times when the telephone circuits are least used.

(II-p-q) Fundamentally, interference to telephone circuits by power circuits in normal operation is largely due to the existence of harmonics in the currents and voltages. While the complete elimination of these harmonics seems impracticable, still beneficial results may be obtained by practical efforts in this direction and the Committee feels that the two general provisions as to the wave form of rotating machines and the exciting current of transformers are of great importance both from a practical standpoint and also as enunciating a general principle. The matter of generator wave form particularly is of importance for all types of systems. The provision with reference to the exciting current of transformers, while desirable in all cases, is particularly so on grounded star-connected systems.

(III) Certain of the measures in II, particularly those referring to power system operation, which are helpful in mitigating inductive interference, have been recommended to apply to existing parallels.

(IV) Since these rules are designed for the protection of communication circuits, it is proper that the companies operating such circuits be given the right to waive any measures of protection which they may in any particular case consider unnecessary.

(V) The Committee has undertaken no investigation of cases of parallelism with alternating-current railways, but as the seriousness of this class of exposure is recognized, it was thought desirable that it be referred to specifically.

FUTURE WORK

The further work necessary in order to secure the information essential as a basis of determining more explicit and effective rules than those herein recommended, is particularly concerned with the subjects of transpositions and residual voltages and currents. In order to cover these subjects in as effective and economical a manner as possible it is thought that the procedure should be along the following lines:

1. Experimental study of transpositions, which includes the determination of:

a—the practical effectiveness of transpositions in both power and communication circuits as a means of reducing induction arising from balanced voltages and currents; involving considerations of different coordinated transposition schemes, particularly with different lengths of power circuit "barrels."*

b—the practical effectiveness of transpositions in communication circuits as a means of reducing inductive interference arising from residual voltages and currents; involving considerations of different systems, particularly different lengths of balanced communication circuit transposition sections.

c—the influence of imperfect electrical balance of communication circuits in impairing the effectiveness of transpositions.

d—the practical effectiveness of transpositions in a power circuit isolated from ground as a means of balancing the electrostatic capacities to earth of the several conductors, and thereby reducing residual voltages and currents; involving considerations of the relative efficiency of different lengths of power circuit barrels.

2. Experimental study of the causes and effects of residuals, including:

a—a comparison of the different types of power system connection and apparatus in common use and their characteristics in respect to the production of residuals, particularly harmonic residuals.

b—means to be employed in limiting residual voltages and currents.

c—a determination of the minimum values of residual voltages and currents which will produce harmful inductive interference.

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*See Appendix III, page 1474.

It is thought that these two studies could progress simultaneously. The work indicated under (1) could best be done on an actual parallel selected to be as uniform and as free from secondary disturbances as possible. Some preliminary work has been done along these lines which indicates the best methods of procedure and this should facilitate the carrying out of the investigation.

The study mentioned under (2) consists in part of an investigation of the characteristics and magnitude of residual voltages and currents in typical power systems, both those with grounded neutrals and systems entirely isolated from ground. A part of the study of residuals is logically related to the study of transpositions and could be carried out in connection with the study outlined under (1) and at the same time and place.

In addition to the above the Committee has already arranged for the investigation of the two following subjects:

1—a determination of the detrimental effect of extraneous currents on a telephone circuit as a function of the frequency, including a determination of the maximum amount of extraneous current, of different frequencies and combinations of frequencies, which is allowable in a commercial telephone circuit.

2—a determination of the effects of extraneous current of different amounts and characteristics, in limiting the speed of telegraph operation.

This work is now in progress.

APPENDIX I

HARMONICS

Any complex electrical wave of periodic structure may be resolved into component sine waves of suitable amplitudes and phase differences, having frequencies which are in integral relation to the fundamental frequency. The simple sine wave of lowest frequency is termed the fundamental, and those of higher frequency are termed harmonics of the fundamental wave. The fundamental may be considered the first harmonic. The analysis of a periodic wave into its constituent sine waves or harmonics is not merely a mathematical conception or process but is in accordance with the facts of electricity and acoustics.

In general, alternating-current systems, by virtue of their inherent characteristics, do not permit the existence of harmonics other than odd integral multiples of the fundamental frequency, *i.e.*, 3rd, 5th, 7th, 9th, 11th, etc., harmonics. Such harmonics may exist in either or both the current and voltage waves of a power system.

Commercial frequencies of power transmission in California are 25, 50 and 60 cycles per second. The power systems, so far investigated, operate at a fundamental frequency of 60 cycles per second. The investigation has shown harmonic currents and voltages of appreciable magnitude up to the 35th harmonic. On one system the 23rd (corresponding to a frequency of 1380 cycles per second) has been found to be prominent. Induced currents and voltages in parallel communication circuits have been observed corresponding to these harmonics.

The detrimental effect of the induced voltages and currents in parallel communication circuits depends, in general, upon their magnitude and upon the frequency of the induction as compared with the operating frequency of the communication circuit. The presence of extraneous current of a frequency approaching that of normal operating frequency of the communication circuit has a more injurious effect than the same amount of current of a frequency far removed from the operating frequency of the circuit.

The frequency of the voice currents flowing in a telephone circuit ranges from about 200 cycles per second up to possibly 2000 cycles per second. The average voice frequency is considered to be approximately 800 cycles per second, and at about this frequency the telephone receiver is most sensitive. It is on account of these considerations that extraneous currents of the higher frequencies, arising from the harmonics of a power system, are relatively more detrimental to telephone service. The harmonics of the power systems have been found to be responsible for the greater portion of the inductive interference to telephone service, under normal operating conditions of parallel power circuits. Any extraneous current of a frequency within the audible range produces a disturbance which impairs the efficiency of a telephone circuit. The combined effects of all extraneous currents present, of frequencies within the range of audition, constitute the humming "noise" heard in the receiver of a telephone circuit which is subject to induction.

The effect of currents of the fundamental frequency (60 cycles or less) on telephone circuits is relatively unimportant as compared to that of higher harmonics, owing to the fact that the fundamental approaches the lower limit of audible frequencies. However, if the induction due to the fundamental becomes sufficiently great, constituting a physical hazard, or of such magnitude as to operate the protective devices on the telephone circuits or interfere with superimposed telegraph service or other grounded signaling devices, it is then of great importance from the standpoint of interference.

In regard to the effect of extraneous currents on the operation of telegraph circuits, for reasons analogous to those given above, such circuits are relatively more affected by extraneous currents of fundamental frequency or of the frequencies corresponding to the lower harmonics such as the 3rd and 5th.

At the present time the American Telephone and Telegraph Company is undertaking, on behalf of the Joint Committee on Inductive Interference, an extensive series of tests in regard to the detrimental effect of extraneous currents of various frequencies on the intelligibility of telephone conversation. In addition, this company, in conjunction with the Western Union Telegraph Company and the Postal Telegraph Cable Company, is undertaking an investigation of the effect of extraneous currents on the operation of telegraph circuits and apparatus of different types.

Harmonic currents and voltages in power circuits arise from many causes. Generators or other rotating machines do not, in general, produce pure sine waves of fundamental frequency. This is due to several features in the design of the apparatus. A certain amount of distortion of wave form, with the consequent introduction of disturbing harmonics, is inherent with the use of transformers. This distortion of wave form is due to hysteretic action in the iron core of the transformer. The distortion varies in character and magnitude with the saturation and characteristics of the iron employed. Certain connections of transformers are possible which will suppress the third harmonic and its multiple in a three-phase power system. The fact that practically all inductive interference to telephone circuits is due to the harmonic currents and voltages, renders it important that an effort be made to obtain rotating machinery for use in power systems which produces as nearly as is reasonably possible pure sine waves of fundamental frequency, and also that an effort be made to obtain transformers and to arrange connections of the same in such a manner as to reduce as far as practicable the distortion of wave form.

APPENDIX II

BALANCED AND RESIDUAL VOLTAGES AND CURRENTS

This appendix comprises the four following sections:

1. Analysis of Voltages and Currents and Discussion of the Effects of their Components.
2. Causes of Residual Voltages and Currents.
3. Means for Preventing or Reducing Residual Voltages and Currents.
4. Discussion of Tests.

1. *Analysis of Voltages and Currents and Discussion of the Effects of their Components*

To facilitate the analysis of inductive effects in parallel communication circuits, arising from a power circuit, the voltages and currents of the power circuits can be conveniently regarded as consisting of components which exhibit distinct characteristics and which may be treated separately.

Considering a three-phase circuit having equal voltages between any two conductors, the voltages to ground from the conductors can be resolved into two sets of components, balanced components and residual components. Since the voltages between any two conductors are equal, the voltages between the conductors may be graphically represented by three vectors forming an equilateral triangle. The potential of the ground may be represented by a point which may be inside or outside of the triangle, depending on the magnitude and character of the residual voltage, and the actual voltages to ground from the conductors may be represented by three vectors drawn between the point representing the ground potential and the corners of the triangle. The balanced components of the voltages to ground from the conductors consist of three equal voltages whose vector sum is zero and which are therefore displaced one-third cycle in time phase with respect to one another. These balanced components may be represented by three vectors drawn from the center of the equilateral triangle to the corners. The residual components of the voltages to ground from the conductors consist of three equal voltages which are in phase with one another and which may be represented by three identical vectors drawn from the point representing the ground potential to the center of the equilateral triangle. If the residual voltage is zero the point representing the ground potential will be at the center of the triangle. The residual voltage of the system is defined as the vector sum of the voltages of the three conductors to ground. It is therefore, by definition, three times the residual voltage of the individual conductors, or three times the equivalent single-phase voltage of the three conductors in parallel with respect to the earth. It should be noted that the inductive effect of the residual voltage is equal to that of a single-phase voltage between ground and the three conductors in parallel equal to the residual voltage of the individual conductors or to one-third the residual voltage of the system.

If one conductor is grounded the residual components (assuming the voltages between wires remain unchanged) will each equal the voltage between conductors divided by the square root of three, and the residual voltage of the system will be equal to the voltage between conductors multiplied by the square root of three.

If a power circuit consists of a single conductor with ground return, the residual voltage will be equal to the voltage from the conductor to ground.

The currents flowing in the three wires of a three-phase, three-wire circuit can be considered to be composed of three sets of currents; namely, (1) balanced components consisting of equal currents in each of the three line wires whose vector sum is zero, and which are, therefore, displaced one-third cycle in time phase with respect to one another; (2) a single-phase current flowing in a loop composed of two of the line wires; (3) a residual current divided equally between the three line wires and returning through the earth. The residual current of the three-phase circuit is defined as the vector sum of the three line currents. It is, therefore, the equivalent of a single-phase current through the three line conductors in parallel, with the earth completing the circuit.

In the case of a power circuit consisting of a single conductor with a ground return the entire current flowing in the conductor is residual.

In the above discussion, reference is made to three-phase. three-wire power circuits, but the analysis there given may be generalized so as to apply to a power system of any number of phases. Most electrical power transmission systems are of the three-phase, three-wire type and subsequent statements will apply particularly to such systems, unless otherwise stated.

At a point in the vicinity of a power circuit, such as might represent the location of an element of a communication circuit conductor, the resultant electromagnetic field due to the balanced currents would be zero if the power circuit conductors were equidistant from the point (disregarding the effect of the earth). In general, the power circuit conductors are not exactly equidistant from such point, and therefore the resultant electromagnetic field due to balanced currents is not zero. For this reason, the balanced currents in the power circuit have unequal effects on the communication circuit, hence there is a resultant induction. For residuals, there is, in general, a much greater inequality in the distances between the affected conductors (or circuits) and the sides of the residual circuit (power conductors in parallel one side, earth other side) than in the distances to the several power conductors, which constitute the circuit for the balanced components. Thus the resultant electromagnetic field due to residual currents is large in comparison with the field set up by balanced currents of the same magnitude. It may be noted that the electromagnetic forces at any point due to residual currents in the different power conductors are in the same time phase, hence the inductive effects of all the residual components are cumulative and not differential as in the case of the balanced components.

In a similar way it may be shown that residual voltages produce proportionately far greater inductive effects than balanced voltages.

Computations based on the physical characteristics of two of the parallels investigated show that, for an exposure near Salinas for eight miles with a 55,000-volt line on the opposite side of the county road from a communication line, one ampere of residual current produces as much induction in a ground return communication circuit as would forty amperes of balanced current; and one volt residual produces as much induction as one hundred and ten volts balanced. Similar computations based on the physical characteristics of an exposure between Santa Cruz and Watsonville, where the communication circuits are paralleled for seventeen miles by a 22,000-volt line on the opposite side of the county road, show that one ampere residual produces as much induction in a ground return communication circuit as would two hundred and forty amperes of balanced current; and one volt residual produces as much induction as twenty-five volts balanced. All of the above comparative values are for current and voltages of 60 cycles frequency.

The above values illustrate the relative induction-producing powers of balanced and residual currents and voltages in two specific cases. Such values will vary considerably for different parallels, but these cited may be taken, in a general way, as indicative of the relative severity of the effects on a single conductor produced by these two factors. Such values for a unit length of non-transposed circuit in any given parallel, are dependent upon the separation, height, and configuration of the conductors of the two classes of circuits, and upon the character and condition of the ground and neighboring objects. For the entire parallel, or total length of exposure, these values are further dependent upon transpositions. The actual amount of induction arising from each of the two components depends also upon the actual magnitudes and the frequencies of the components in the power circuit.

It will be shown in Appendix III that inductive interference arising from balanced currents and voltages can be reduced by proper transpositions in the power circuit, but that power circuit transpositions do not reduce the inductive interference produced in a parallel communication circuit by residuals. Residual currents and voltages act inductively to produce the same effects as a single-phase grounded circuit operating with the three line conductors in parallel. This generally represents the worst possible condition from the standpoint of inductive interference. Transposing the conductors of the power circuit cannot reduce the inductive interference arising from residuals, except in so far as the magnitude of the residual voltages and currents is reduced by such transpositions. The effect of power circuit transpositions on the magnitude of these components is discussed below.

In the detailed discussion of transpositions in Appendix III it is shown that transpositions in a communication circuit can reduce the induced voltages from residuals only as between the two sides of a metallic circuit.

In view of the above it is evident that attention must be given to the problem of restricting residuals to amounts which do not cause material interference either to grounded communication circuits or to properly transposed and balanced metallic circuits.

2. *Causes of Residual Voltages and Currents*

While a degree of balance of the voltages and currents of the power system may be obtained which satisfies all the practical demands of power operation, this may not be sufficient to prevent the production of residuals sufficient to cause serious inductive interference to parallel communication circuits.

Residual currents and voltages may arise from one or more causes which act singly or together. The principal sources of residual currents and voltages are:

1. Unbalanced loads between the three phases and the neutral of a grounded star-connected system.
2. The introduction of the third harmonic and its odd multiples as residual current and voltage due to certain apparatus and connections employed on a grounded star-connected system.
3. Unbalanced capacity and leakage between the several phases of the system and ground. This applies more particularly to systems isolated from ground.

There are two principal types of commercial three-phase power circuits used in California:

1. The grounded neutral circuit or network in which all important generating points have a grounded neutral and in which all or part of the receiving points may be connected with a grounded neutral. No resistances are inserted between the neutrals and ground.
2. The isolated circuit or network which normally has no metallic connection to ground at any point.

The characteristics of the grounded neutral system with particular reference to residuals are as follows:

Under Normal Conditions.

(a) The impedances between line conductors and ground are determined very largely by the load impedances of the transformers. With balanced loads the residual voltage other than the third harmonic and its odd multiples may be eliminated.

(b) The effect of unbalanced loads on the residual voltage is small, as the tendency of generators and transformers is to maintain equal voltages between the several conductors and ground.

(c) With balanced loads the residual current, other than the third harmonic and its odd multiples, may be eliminated.

(d) Unbalanced loads between line and neutral cause corresponding residual currents, which will be large if the unbalance is large, as such unbalanced load currents flow through the neutral to earth.

(e) The varying permeability of the iron in star-connected transformers with grounded neutrals introduces the third harmonic and its odd multiples as residual voltages and currents. The use of delta-connected secondary windings reduces this effect greatly below that of star to star connections.

(f) Grounded star-connected generators connected directly to the line or through grounded star to star-connected banks of transformers, may introduce the third harmonic and its odd multiples as residual voltages and currents.

Under Abnormal Conditions

(g) A ground on one phase short-circuits that phase through the neutral connection and causes a residual current throughout the whole length of the circuit, this current being practically equal to the short-circuit current to ground on that portion of the circuit between the sources of power supplying the fault and the point where the circuit is grounded. A large residual voltage (approaching as a maximum 58 per cent of the voltage between phases) will be created in proximity to the fault, and, if the low-tension side of the receiving transformers is star-connected, throughout that portion of the circuit between the fault and such receiving transformers. If the neutral of the receiving transformers is isolated, the short-circuit current will exist only between the source of supply and the fault and there will be no residual current between the fault and such receiving transformer. The above-mentioned residual voltage will in this case exist not only in proximity to the fault on the supply side but also throughout the length of circuit from the fault to the receiving transformers. The power circuit is rendered inoperative.

(h) An open condition of one phase causes a large residual current, as the unbalanced load currents of the other two phases must flow through the neutral to earth. A large residual voltage will exist beyond the fault if the low-tension side of the receiving transformers is star-connected. The power circuit may not be rendered inoperative for three-phase supply beyond the fault, in case the receiving transformers are grounded star-delta connected.

The characterisitics of the isolated system with particular reference to residuals are as follows:

Under Normal Conditions

(a) The impedances between line conductors and ground are determined by the electrostatic capacities and the leakage between the several conductors and ground. With balanced loads a residual voltage may exist due to unbalanced capacity and leakage. Such residual voltage as is due to unbalanced capacity may be eliminated by transposing the circuit so as to equalize the electrostatic capacities to ground of the several phases. If there are single-phase branches making the total lengths of the three conductors unequal, this will introduce inequalities among the capacities to ground which it may not be possible to balance by transpositions. Inequalities in capacity or leakage result in unequal voltages between the different line conductors and ground.

(b) The effect of unbalanced loads on the residual voltage is very slight.

(c) With balanced loads a small residual current consisting of unbalanced charging current may flow, due to non-uniform distribution of unbalanced capacity and leakage.

(d) Unbalanced loads have but a slight effect upon the residual current.

(e) The transformers cannot introduce the third harmonic and its odd multiples as residual voltages or currents.

NOTE: Due to unsymmetrical three-phase connections sometimes employed (such as open-delta and Scott connections) the third harmonic and its odd multiples may appear in the voltages between lines and in the line currents, creating dissimilarities in the wave forms for the several phases. These harmonic components of the line voltages and currents are affected by unbalanced capacity and leakage in the same way as any other components as may appear in the residuals. It should be noted, however, that such harmonics are not impressed directly upon the line as residuals as is the case with grounded neutral systems.

(f) The generators cannot introduce the third harmonic and its odd multiples as residual voltages and currents.

NOTE: If a two-phase generator containing a third harmonic in its voltage wave supplies the line through Scott or other two- to three-phase transformer connections the third harmonic will appear in the voltage between lines. Subject to the conditions of the circuit as regards capacity and leakage balance, this harmonic along with all others may or may not appear in the residuals.

Under Abnormal Conditions

(g) A ground on one phase causes a large residual voltage (173 per cent of the voltage between phases) throughout the entire length of the circuit. A residual current will be created in proximity to the fault, its magnitude increasing with the extent, voltage and frequency of the system. The power circuit may not be rendered inoperative and the power company operators may be unaware of the existence of the abnormal condition. In some cases the residual voltage and current are greatly augmented by the resonant effects accompanying arcing grounds.

(h) An open condition of one phase may cause a large residual voltage, a certain amount of residual current will flow, due to the interchange of unbalanced charging current, between sections of line on either side of the fault. The power circuit is rendered inoperative for three-phase supply beyond the fault.

A consideration of the characteristics of the two types of systems indicates that under normal operating conditions, with balanced loads upon all phases, the residuals of the grounded neutral system may be limited to the third harmonic and its odd multiples. The magnitude of these harmonics is dependent largely on the type of connection on the low-tension side of the transformer banks, the delta being preferable to star connection. Under the same condition the residuals of the isolated system may be limited to those resulting from unbalanced leakages to ground, which should be small on a well-maintained system. The effect of an unbalance in the loads connected between conductors upon the residuals of either type of system is small, while the effect of an unbalance in the loads connected between conductors and ground upon a grounded neutral system is to cause a residual current which is proportional to the amount of such unbalance, which will be large if the unbalance is severe. The residual current due to this cause, consists of the fundamental and all harmonics present in the line currents, in addition to which the third and its odd multiples are introduced as before by the varying permeability of the transformer iron, and in some cases by the generators.

Under abnormal conditions both types of systems give rise to residuals which are liable to cause interruption and damage to parallel communication circuits. The most frequent abnormal condition which produces severe interference is an accidental ground. A ground on one phase of a grounded star-connected system creates a severe and wide-spread electromagnetic unbalance, giving rise to corresponding inductive effects. This is accompanied by an electrostatic unbalance in the vicinity of such ground. On the lower voltage systems this latter effect is relatively of little importance. On the other hand, a ground on one phase of an isolated system creates a severe and wide-spread electromagnetic unbalance, giving rise to corresponding inductive effects. This is accompanied by an electromagnetic unbalance in the vicinity of the ground. On small low-voltage isolated systems, such electromagnetic unbalance is relatively of little consequence, but it should be noted that with increased voltage and extent of the system such effects do become of great importance, giving rise to electromagnetic disturbances in exposed communication circuits in addition to the electrostatic disturbances.

The magnitude of the inductive effects from either type of system is dependent upon the character of the exposure, extent of the power circuit and other factors which render it impossible with the information at hand to draw a definite conclusion as to the relative total amounts of interference inherent with the two types of system. Furthermore, it is not necessarily true that either type of connection has an advantage from the inductive interference standpoint for power systems of all sizes and voltages.

3. *Means for Preventing or Reducing Residual Voltages and Currents*

To minimize or prevent residual voltages and currents due to cause 1, it is necessary to equalize as closely as practicable at all points the load between the several phases of the circuit and the neutral, or to remove the ground path for unbalanced load currents, thus allowing a grounded neutral at one end of the circuit only. As it is difficult, if not impossible, to maintain all loads in a state of equilibrium at all times, the latter method has the advantage of greater reliability.

Single-phase connections to ground should not be employed. Where single-phase loads or unbalanced three-phase loads must be supplied, the transformers supplying such loads may be connected across the line wires, or may be connected star to delta, with the neutral not grounded. It should be noted that single-phase or unbalanced three-phase loads on the low-tension or delta side of grounded star to delta-connected transformers produce effects on the high-tension side similar qualitatively to single-phase loads between line and ground, but these effects are greatly reduced in magnitude by the inherent balancing influence of transformers so connected, due to the fact that all three transformers participate in supplying such a single-phase load.

Residuals which arise from cause 2 may be greatly reduced by means of certain types of connections for generators and transformers. Thus for example, connecting the secondary windings of the transformer banks in delta largely suppresses these components of the residual voltage and current but does not entirely prevent them. Where the transformers are connected grounded star to star, these components can be, to a certain extent, kept out of the line by the use of a second bank of transformers having a delta connection on one side and a star connection on the side in common with the first bank, with the neutrals interconnected.

The possibility of the introduction of third-harmonic residuals on the line due to the use of grounded star-connected generators may be avoided by the employment of transformers between generators and line, the windings on the generator side of the transformers being isolated from ground.

To eliminate or reduce residual currents and voltages which may be due to cause 3, it is necessary to transpose the conductors of the power circuit so as to equalize the electrostatic capacities of the several phases to ground, and this equalization must be attained within distances sufficiently short to prevent the accumulation of large unbalances. With a horizontal arrangement of conductors, the capacities to ground are more nearly equal that with the triangular or vertical arrangement. It is probable that the electrostatic capacities are the controlling factors in determining the residual voltage and current of an isolated system under normal operation, and while an investigation of the extent to which such residuals may be reduced by properly spaced transpositions has not yet been made, it is reasonable to suppose that transpositions will be substantially effective. The effect of unbalanced leakage cannot be controlled, except through proper construction and maintenance of the power system. It is to be noted that the maintenance of the system free from accidental grounds and partial grounds becomes increasingly difficult the larger the extent of the power network.

On a grounded star-connected system, the electrostatic capacity and the leakage of the several phases to ground are relatively less effective in producing residual voltage, as on such systems the voltages to ground are determined almost entirely by the generators and transformers.

4. *Discussion of Tests.*

Having given a general analysis of the causes and effects of and means to reduce residual currents and voltages, it is desirable to call attention to the results of tests which have been conducted, which have a bearing on this subject.

At Salinas, the effect of grounding or isolating the neutral of the auto-transformers, which have also a secondary delta winding, was investigated. These auto-transformers are supplied at 55,000 volts over a transmission line which parallels the circuits of The Pacific Telephone and Telegraph Company in what have been termed exposures No. 1 and No. 2. These auto-transformers in turn supply a 33,000-volt line of the Coast Valleys Gas and Electric Company, extending from Salinas to King City, a distance of approximately 45 miles, and paralleling throughout practically this entire length, the coast route toll lead of The Pacific Telephone and Telegraph Company. These same telephone circuits are involved in the parallels with the 55,000-volt line north of Salinas. In addition to supplying the King City line this bank of auto-transformers at Salinas supplies a 22,000-volt line extending to Monterey, a distance of approximately 18 miles. Aside from the ground on the transformer neutral at Salinas, there are no grounds on either the 33,000-volt line or the 22,000-volt line. The 55,000-volt line supplying the Salinas transformers is energized at the Guadalupe substation of the Sierra and San Francisco Power Company, approximately 73 miles distant from Salinas, through grounded star-connected auto-transformers, which have delta-connected secondary windings, and which are supplied by the 104,000-volt line of this same system which operates with grounded neutral connection at its main generating station and substations. It will be understood from this statement of conditions that the neutral current at Salinas is not identical with the residual current of any one of the three high-tension lines which are connected together by these auto-transformers. The condition of the Salinas neutral affects the induction arising from the several exposures through its effect on the residual currents and voltages of the high-tension lines connected to the auto-transformers at that point. A representative value of the neutral current at Salinas during these tests is 0.3 ampere. It is composed almost entirely of the ninth harmonic, the fundamental and the third harmonic, their magnitudes decreasing in the order named. With the power system in normal operation, isolating the neutral of the auto-transformers at Salinas did not greatly affect the resultant induction in the particular exposures under observation. The values in the following table, taken from the data of the tests, indicate the effect of the condition of this neutral on the residual currents of the 55,000-volt and the 33,000-volt lines.

RESIDUAL CURRENT AT SALINAS—AMPERES.

Order of Harmonic	55,000-volt line.		33,000-volt line.	
	Neutral at Salinas		Neutral at Salinas	
	Grounded	Non-Grounded	Grounded	Non-Grounded
1	0.120	0.057	0.061	0.073
3	0.054	0.160	0.075	0.120
9	0.073	0.100	0.120	0.075

Two reasons may be given for the fact that the condition of the Salinas neutral does not greatly affect the resultant residual current of these lines: (1) the load balance on these lines is such that a relatively small amount of load current flows through this neutral: (2) as three high-tension lines are connected together by these auto-transformers, opening their neutral connection to ground does not completely eliminate the path for the residual current of any one of the three lines, since it may then flow to earth through the admittance to ground of the other two lines.

These particular conditions are not commonly found, but a similar condition, in that there is a path to ground for residual current aside from the neutral connection, prevails in any case where the power circuit extends for a considerable distance beyond such neutral connection. The investigation showed, for the conditions which applied to the 55,000-volt line, that removing the neutral ground connection beyond the parallel decreased the fundamental and increased the third and ninth harmonics in the residual current as shown in the above table. It is not be concluded, however, from this one case, that the third harmonic and its odd multiples in the residual current would in all cases be increased by removing the neutral ground connection of a bank of receiving transformers where the circuit extends beyond the point of measurement of such residual current. If the circuit is terminated at the transformer bank, the removal of the neutral ground connection must eliminate the residual current at that point.

In the case of the 33,000-volt line, the grounding of the neutral at Salinas merely gave another and nearer grounded neutral point on the line supplying power but did not give a grounded neutral point in each direction from the point of measurement of the residuals as it did in the case of the 55,000-volt line. As the 33,000-volt line has no grounded connection beyond Salinas, the residual current must flow to ground entirely through the admittance of this line to ground. The residual current, therefore, diminishes to zero at the King City end of the line. Isolating the neutral of the Salinas transformers affects the constituents of the residual currents in this line arising from the Salinas transformers, and those impressed by the 55,000-volt line, in such a way that they combine vectorially to give a different resultant from that with the Salinas neutral grounded. The result is to increase the fundamental and third harmonic and to decrease the ninth harmonic when the neutral is isolated. The residual current in the 22,000-volt line was not determined, but residual voltage measurements were made with the Salinas neutral isolated and grounded and the results are included in the following table, from which it may be noted that the fundamental, third and ninth harmonics were all greater with the Salinas neutral isolated.

The banks of star-connected auto-transformers at the Guadalupe and Salinas substations are provided with closed-delta secondary windings, which in the case of Salinas supply power for local consumption. An experimental opening of the delta at Salinas demonstrated, as would be anticipated, that the use of such delta-connected secondary windings reduces, in a large measure, the third harmonic introduced by these transformers in comparison with its value without the use of such delta-connected windings. If grounded star-connected transformers are used, it is important, therefore, from the standpoint of induction, to provide such transformers with closed-delta-connected secondary windings or with other means of reducing the third harmonic and its odd multiples. Such means may, however, in some cases be insufficient to reduce the residuals to such low values that they will not produce harmful inductive interference to parallel communication circuits.

The investigation on the system of the Coast Counties Gas and Electric Company shows results which are summarized in the following table with reference to the residual current and residual voltage. Santa Cruz, where the measurements were made, is 20 miles from one source of supply and 75 miles from the other end of the line, where power was also supplied. For the sake of comparison the averages of the residual voltage of the 22,000-volt line between Salinas and Monterey, a distance of 18 miles, are also given:

Order of Harmonic	Residual Voltage—volts.			Residual Current amperes
		Salinas Neutral		
	Santa Cruz	Grounded	Non-Grounded	Santa Cruz
1	360	50	90	0.094
3	—	150	320	—
9	19	40	50	0.021
11	14	—	—	0.017
13	10	—	—	—
23	14	—	—	—

The system of the Coast Counties Gas and Electric Company is isolated from ground and employs a number of Scott-connected and open-delta-connected transformers. The residuals at Santa Cruz on this system are composed principally of fundamental, ninth and eleventh harmonics. The fundamental is predominant. The third harmonic is absent or too small to measure accurately. It should be noted here that the use of Scott- and open-delta-connected transformers permits the third harmonic and its odd multiples to exist in the line voltages and currents of a three-phase isolated system. In all probability the residuals on this system are caused by unbalanced admittances to ground of the power line conductors. As has already been pointed out, that part of the unbalance due to electrostatic capacity could be greatly reduced by properly spaced transpositions in the power circuit. In contrast to the results at Salinas, the residuals of this system exhibit a prominent fundamental and the absence of, or relatively small amounts of, the third harmonic and its odd multiples.

APPENDIX III

Transpositions

The sources of the disturbances in communication circuits, which arise from parallel power circuits, have been treated in the first section of the preceding appendix. The effect of transpositions on the induction in communication circuits produced by parallel power circuits will now be considered.

This appendix comprises the four following sections:

1. Effect of Transpositions in Reducing Induction.
2. Characteristics of Present Transposition Systems.
3. Characteristics of Proposed Transposition Schemes.
4. Results of Tests.

1. *Effect of Transpositions in Reducing Induction.*

Transposing a circuit is the interchanging of the positions occupied by the conductors.

By transposing a power line the phase of the resultant electromagnetic field due to balanced currents and the phase of the resultant electrostatic field due to balanced voltages is changed, and the induction is reduced by the production of neutralizing effects in the neighboring lengths of a parallel conductor. Thus, by locating the power circuit transpositions so that each conductor occupies all of the several possible conductor positions for equal distances, a section or "barrel" is obtained within which the resultant induction on a parallel conductor due to balanced currents and voltages is completely neutralized, neglecting attenuation and remanent electrostatic effect and assuming the parallel is uniform throughout the barrel.

Inasmuch as residual currents and voltages are in phase in the several conductors, the transposition of the power circuit does not reduce the inductive effects therefrom in a parallel conductor, except as the magnitudes of the residual currents and voltages are reduced by the power circuit transposition. (See Appendix II).

As usually constructed, the conductors of a telephone circuit are close together as compared with their distances to a power line, and the circuit is usually isolated from ground. Could the conductors of a metallic communication circuit be located at the same point in space, as is approximately true of a pair of wires twisted together, the resultant electromagnetic and electrostatic induction between the sides of the communication circuit would be zero. The voltage induced along the conductors of the telephone circuit and the induced voltage to ground would be present but would not be effective in producing any voltage between the conductors of the telephone circuit, provided the capacity and leakage to ground of each side of the telephone circuit were equal. On overhead lines the conductors of a metallic communication circuit must be at least several inches apart, hence in general when paralleled by a power line, the resultant electromagnetic and electrostatic induction in the two conductors will be unequal in magnitude. The result is that a voltage exists between the sides of the circuit which causes a current to flow in apparatus connected between the conductors, such as a telephone receiver.

Transpositions in communication circuits tend to equalize the induction in the two sides of the circuits by exposing each side equally to the influence of the power circuit, that is, by reversing in successive lengths the phase of the induction between the two sides of the circuit.

In an exposure where the induction from unbalanced currents and voltages would be completely neutralized by the power circuit transposition system if there were no communication circuit transpositions, or where such induction would be completely equalized by the communication circuit transpositions if there were no power circuit transpositions, this induction will practically always be partially cumulative if both power and communication circuit transpositions are installed without due reference to each other. It should be noted, however, that the maximum disturbances which may be set up in a parallel communication circuit by balanced currents and voltages in the power circuit will be present when neither the power circuit nor the communication circuit is transposed. Hence it is very important that the power and communication circuit transpositions be properly located with respect to each other and in this way only can the maximum benefits from the transposition be derived.

Induction from residual currents and voltages is reduced by communication circuit transpositions.

If the communication circuit has a ground return, it cannot be transposed and the power circuit transpositions alone will be effective in reducing interference arising from the balanced currents and voltages. Also, the induction into a ground return communication circuit from residual currents and voltages is not affected by transpositions, except indirectly, as previously stated. It is possible, though not of general practical application, to obtain the effect of a transposition in a grounded alternating-current power or communication circuit by means of a transformer or repeating coil.

Induction between wires and ground is harmful to metallic as well as to ground return circuits, for in case the metallic circuit is not perfectly balanced electrically, such induced voltage forces a current to circulate in the metallic circuit through the terminal apparatus. It is not practical to maintain communication circuits in a state of perfect balance at all times.

2. *Characteristics of Present Transposition Systems.*

The transposition systems used on long distance metallic telephone circuits are designed primarily to reduce the "cross-talk" or induction from one telephone circuit into another and provide for a high degree of balance between any circuit and all others on the line.

The length of standard balanced telephone transposition sections used by The Pacific Telephone and Telegraph Company is approximately eight miles (more exactly, 41,600 feet), and this is representative of the length of sections of the transposition systems used by other companies operating similar lines. To improve the transmitting qualities of telephone circuits used for long distance work, loading coils are introduced in certain circuits at the ends of the standard transposition sections. Uniform spacing of the telephone "S" poles (end poles of transposition sections) is an important consideration in the application of loading. It is important that the induction be neutralized in each section between loading points, as these are points of discontinuity in the circuits.

The system now used also provides for the transposition of every circuit at actual intervals ranging from one-quarter mile to two miles, the average intervals for different circuits varying from approximately one-quarter mile to three-quarters of a mile, hence every circuit is to a certain extent balanced to induction from parallel power circuits.

In addition to the metallic circuits composed of two conductors, the telephone companies employ phantom circuits which are made up from two physical (two-wire) circuits. Each "conductor" or side of the phantom circuit consists of the two conductors which form one physical circuit. As usually made up, the physical circuits occupying adjacent horizontal positions are used for the phantom circuit. Hence, the average distance between the sides of the phantom circuit is equal to twice the distance between the conductors of the physical circuits. Due to the greater distance between the sides of the phantom circuit as compared with the physical circuits, the phantom circuits are more subject to inductive interference than the physical circuits. The phantom circuit possesses marked advantages in economy and transmission efficiency over the physical circuits composing it, hence, is extensively used for the longer distances. The transpositions in the phantom circuits are spaced at average intervals, for different circuits, varying approximately from three-quarters of a mile to two miles.

The purpose of transposition systems applied to power circuits has been to reduce the disturbance in parallel communication circuits and in some cases to equalize the separation of the pairs of conductors forming the several phases. Usually when transpositions have been applied to power circuits to reduce the disturbance in existing parallel communication circuits, one or more complete barrels have been provided within the total length of the exposure. The best obtainable results from power circuit transpositions will be had only when they are located with due regard to the transposition points of the communication circuit. No such practise as this has been followed in the past. The transposition systems heretofore applied to parallel power and communication circuits have therefore failed to meet the requirements for maximum effectiveness. Hence, balanced currents and voltages in the power circuits have, in general, caused more disturbance than necessary in parallel communication circuits.

3. *Characteristics of Proposed Transposition Schemes.*

It would be possible to fulfill the conditions for balance with regard to induction arising from balanced currents and voltages, by cutting a " barrel " into the power circuit between successive communication circuit transpositions. Inasmuch as telephone transposition points are ordinarily spaced at one-fourth mile intervals, this solution in the case of a three-phase power circuit would necessitate transpositions at an average spacing of one-eighth mile and a minimum spacing of one-twelfth mile, which is impracticable in most cases.

It would be possible to satisfy the conditions for balancing the induction in metallic circuits, from both balanced and residual currents and voltages, by installing any completely balanced system of communication circuit transpositions between each two successive power circuit transpositions. Assuming twelve-mile " barrels " in the power circuit, the conditions for balance could be fulfilled with the present standard telephone transposition system. However, with power circuit barrels of a length such as is essential in most parallels, this solution would require the redesign and relocation of all telephone transpositions in the exposure, involving several times as many transpositions as are normally require, with the liability of interference with the location of loading coils.

Both the above solutions satisfy the conditions for balancing the induction in metallic circuits, arising from residuals, in a length of circuit equal to twice the distance between successive communication circuit transpositions, assuming these are uniformly spaced. In the standard transposition section as now used, balance is thus obtained in distances varying from an average of approximately one-half to four miles.

Between these two comparatively simple but extreme solutions the practical but more complicated solution for general cases is to be obtained. This involves the combination of power circuit barrels of moderate length with a modified communication circuit transposition system designed to procure balance as far as practicable for all circuits. In this way coordinated transposition systems may be designated which are sufficiently flexible to meet the requirements of short parallels and portions of longer parallels separated by points of discontinuity.

In the discussion above with reference to schemes of transpositions, the balances or unbalances mentioned are those which would occur, due solely to the relative locations of transpositions, in an exposure whose physical characteristics are uniform throughout. Even with a scheme of transpositions, balanced in the sense described, applied to both power and communication circuits involved in an actual parallel, there are a number of factors as noted below, which in general are not capable of being taken into account quantitatively and because of which effective neutralization may not be obtained. These factors are:

1. Non-uniformity of separation, configuration and other physical characteristics.
2. Variation in magnitude and phase of the inductive effects along the exposure (applying particularly to the higher frequencies.)
3. Inherent inability of transpositions to completely neutralize electrostatic induction (this remanent effect can be reduced as far as desired by inserting a sufficient number of transpositions.)
4. Imperfect electrical balance of the communication circuit.

While these factors which prevent complete neutralization of the induction cannot be entirely eliminated, their effects can be abated by reducing the length of balanced transposition sections. Thus it is not sufficient merely to install transpositions in both lines so that they are balanced to each other, but, also, it is necessary to take into consideration the length of section within which balance is obtained and to make this length as short as the conditions of the particular case require.

Points of discontinuity, such as abrupt changes in power line current where a material amount of load is taken off, cross-overs, or substantial changes in separation, should, if practicable, be made neutral points (junction points of balanced sections) in the transposition scheme. Where cross-overs occur balance should in general be obtained independently for the portions of the communication line on each side of the power circuit.

The transposition system and the location and spacing of transposition poles are factors of prime importance in the successful operation of telephone lines, on account of the mutual effects among the many circuits carried on such lines. On the other hand, transpositions in power circuits are, relatively, of minor importance in the operation of a power system and from this standpoint the effect of small changes in the location of such transpositions is negligible. Hence, in general, the requirements of the communication circuits are the chief factors which should govern the location of all transpositions in both power and communication circuits.

An individual study is necessary to determine the best procedure for any given parallel, owing to the wide variation in conditions. Thus only is it possible in each case to determine the best location and method of transpositions with regard to the requirements of both power and communication systems.

4. *Results of Tests.*

The investigation at Salinas demonstrated that the induction in a ground return circuit in the exposures concerned, arises principally from the residual voltages and currents while the induction in a metallic circuit shows principally the characteristics of the balanced voltages and currents together with some effect from the residuals. This result was to be expected, as there are power circuit transpositions which reduce the induction in the conductors used as ground return circuits, due to the balanced components, but these transpositions and the transpositions in the telephone circuits are improperly located with respect to each other and therefore are inefficient as regards the induction in the metallic circuits. On the other hand, the telephone transposition system tends inherently to reduce the induction in the metallic circuits, arising from residuals. A study of the relative location of power and telephone circuit transpositions for exposure No. 2 at Salinas, indicated that by modifying the present transpositions of both circuits, it is possible to reduce materially the induction from balanced currents and voltages. Had it been feasible to take the power circuit out of service for the purpose of experimental retransposition, the above scheme, as well as one for the King City exposure, would probably have been installed and the effects thereof experimentally determined. Under the conditions existing, however, it was deemed advisable to postpone the matter of transpositions for both these exposures, pending the acquisition of further information as to the extent to which retransposition would be warranted as a permanent improvement.

The experimental study of transpositions was, therefore, transferred to another point where a power line is not the sole source of supply and can, therefore, be shut down for alterations and tests under special conditions.

The experimental determination of the practical effectiveness of transpositions has not been completed. However, an extended theoretical study of transpositions has been made, including the design of a modified telephone transposition system. This system, which requires many additional transpositions, is more flexible in its properties of coordination with different lengths of power circuit "barrels".

A study made to determine the relative efficiency of various schemes of transpositions designed for the Santa Cruz-Watsonville exposure of The Pacific Telephone and Telegraph Company's toll lead to the 22,000-volt line of the Coast Counties Gas and Electric Company, emphasizes the following general principles:

1. The necessity of proper relative location of power and telephone circuit transpositions.
2. The importance of the effect of cross-overs and the desirability of making them neutral points in the transposition scheme.
3. The necessity of some modification of the telephone transposition system.

APPENDIX IV

APPARATUS

For the proper conduct of its tests and experiments the Joint Committee on Inductive Interference has secured, either through purchase or on loan account from various power and communication interests, apparatus of an aggregate value of over twelve thousand dollars.

The following is a brief schedule of the property in use by this Committee, together with its estimated replacement value:

Buildings (Portable Laboratory)		$ 480.00
Furniture and Fixtures		128.00
Apparatus—Oscillograph	$1,115.00	
Oscillator	600.00	
Motor-Generator Set	260.00	
Meters	1,202.50	
Batteries	100.00	
Condensers	990.00	
Bridges	675.00	
Galvanometers	265.00	
Rheostats	734.80	
Switchboards	135.40	
Misc. Apparatus	1,505.00	
Coils and Relays	645.00	
Transformers	2,412.50	
Miscellaneous	787.00	
Photographic	293.60	11,820.80
Grand Total		$12,428.80

The above property is owned by the Joint Committee on Inductive Interference and various power and communication companies, as follows:

Joint Committee on Inductive Interference	$ 1,251.15
The Pacific Telephone and Telegraph Company and American Telephone and Telegraph Company	8,293.65
Sierra and San Francisco Power Company	2,002.50
San Joaquin Light and Power Company	300.00
Pacific Gas and Electric Company	110.00
Western Union Telegraph Company	235.00
Testing Force	256.50
Total	$12,428.80

APPENDIX V

LIST OF TECHNICAL REPORTS

The following is a list of the technical reports which have been prepared in connection with the investigation of the Joint Committee on Inductive Interference:

Technical Report No.	Subject
1.	General outline of tests to be made at Salinas on parallels between lines of the Sierra and San Francisco Power Company, the Western Union Telegraph Company, the Southern Pacific Company, and The Pacific Telephone and Telegraph Company. (6 pages.)
2.	Summary of results of tests at Morganhill on parallel between lines of the Coast Counties Gas and Electric Company and The Pacific Telephone and Telegraph Company between Morganhill and Gilroy. (8 pages.)
3.	A description of the noise standard in use for measuring noise on telephone circuits in terms of a standard unit. (4 pages)
4.	A description of the instruments and methods used for the measurements of effective values of induced voltages and currents. (2 pages.)
5.	A description of apparatus and connections used in measuring line and residual currents and voltages of power circuits. (6 pages)
6.	Tests of the effects of opening the secondary delta of the auto-transformer bank at Salinas. (7 pages)
7.	Tests of the induction in the block signaling circuits of the Southern Pacific Company paralleled by the Salinas-King City circuit of the Coast Valleys Gas and Electric Company. (4 pages.)
8.	Tests of the induction in the telephone circuits of exposure No. 2 at Salinas under normal operating conditions of the power system, with particular reference to the effects of grounding and isolating the neutral of the Salinas auto-transformers. (16 pages)

9. Experimental determination of the coefficients of induction for residual currents and voltages in exposure No. 2 at Salinas. (4 pages.)

10. Measurements of the harmonics of the neutral current at Salinas. (4 pages.)

11. Investigation of current transformers, ratios, and errors due to the use of current transformers under the conditions of the tests. (21 pages)

12. Formulae for the computation of electrostatic and electromagnetic induction from power circuits in neighboring communication circuits. (18 pages)

13. An investigation of errors in measurements of residual voltage due to the potential transformers used and a discussion of the method of measurement at Salinas. (30 pages)

14. Comparative tests of the noise in exposed telephone circuits with power on and off the 55,000-volt power circuit of the Sierra and San Francisco Power Company between Guadalupe and Salinas. (8 pages)

15. Supplementary to Technical Report No. 8, differing from the earlier report in that the telephone circuits were shielded. Contains a discussion of transpositions. (22 pages)

16. Tests of the induction in telephone circuits exposed to the Coast Counties Gas and Electric Company's 22,000-volt line between Morganhill and Gilroy with the power circuit untransposed and open at Gilroy. (4 pages)

17. Tests of the induction in telephone circuits exposed to the Coast Counties Gas and Electric Company's 22,000-volt line between Morganhill and Gilroy, before and after installing power circuit transpositions. (24 pages)

18. Tests of the effect, on exposed telephone circuits, of grounding one phase of the Coast Counties Gas and Electric Company's 22,000-volt three-phase delta-connected line. (4 pages)

19. Test of the combined effects of the Coast Counties Gas and Electric Company's and the Sierra and San Francisco Power Company's circuits on the telephone circuits in the exposure between Morganhill and Gilroy. (4 pages)

20. Tests of the effect on the residual voltage of transposing the Coast Counties Gas and Electric Company's 22,000-volt line within the exposure between Morganhill and Gilroy. (3 pages)

21. Tests to determine the comparative effect on the noise in the exposed telephone circuits of having the power on and off the Coast Counties Gas and Electric Company's 22,000-volt line between Morganhill and Gilroy, and the effect of shielding the telephone circuit under test by grounding other circuits on the lead. (4 pages)

22. Computation of the coefficients of induction from balanced and residual currents and voltages for the telephone circuits of exposure No. 2 at Salinas. (19 pages)

23. Experimental determination of the coefficients of induction from residual currents and voltages, for the telephone circuits of exposure No. 2 at Salinas—more complete than Technical Report No. 9. (24 pages)

24. Comparison of computations of Technical Report No. 22 with experimental data of Technical Report No. 23. (16 pages)

25. Tests of induction in telephone circuits in exposure between Salinas and King City under normal operating conditions, with the neutral of the Salinas auto-transformers grounded and isolated. (20 pages)

26. Tests of accuracy of measurement of residual current by certain current transformers. (4 pages)

27. Tests of induction in telephone circuits in exposure No. 2 at Salinas with the North Beach steam station energizing the Sierra and San Francisco Power Company's line. Supplementary to Technical Reports Nos. 8 and 15, differing in the source of supply of the power system. (27 pages)

28. Supplementary to Technical Reports Nos. 8 and 15. Voltage lowered 5 per cent at the Guadalupe auto-transformers which supply the power circuit. (20 pages)

29. Determination of impedances of lines, by computations and by measurements—numerous curve sheets and tables. (65 pages)

30. Tests of induction in telephone circuits in exposure Nos. 1 and 2 at Salinas, with the neutral of the Salinas transformers grounded and isolated. (10 pages)

31. Supplementary to Technical Reports Nos. 8 and 15 and more complete. Includes tests with Salinas neutral grounded and isolated and with telephone circuits shielded and unshielded. (29 pages)

32. Supplementary to Technical Report No. 25. (22 pages)

33. Induction in test leads used at Salinas for connecting testing apparatus to the circuits of exposure No. 2 and the effect of such on the measurements of the induction from the exposure. (20 pages)

34. Effect of changes in the insulation resistance of the telephone line on the induction in telephone circuits of exposure No. 2 at Salinas. Also supplements Technical Reports Nos. 8, 15, and 31. (24 pages)

35. General outline of tests to be made at Santa Cruz on the parallel between lines of the Coast Counties Gas and Electric Company and The Pacific Telephone and Telegraph Company. (4 pages)

36. Induction in telegraph circuits of the Western Union Telegraph Company and the Southern Pacific Company in exposure No. 1 between Salinas and San Jose. (8 pages)

37. Noise tests on telephone circuits radiating from Salinas, with the neutral of the Salinas auto-transformers grounded and isolated. (4 pages)

38. General review of tests at Salinas, summarizing reports 1, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 22, 23, 24, 25, 26, 27, 28, 30, 31, 32, 33, 34, 36, and 37. (53 pages)

39. General consideration of transpositions and a study of the results to be expected from the application of various transposition schemes to the Santa Cruz-Watsonville exposure. (36 pages)

40. Method of measurement of capacity and conductance unbalances (2 pages)

41. Harmonic analysis of alternating-current waves, by oscillograph and resonant shunt. Comparison of the methods. (30 pages)

42. Investigation of the current transformers in use at Santa Cruz. to determine their ratios of transformation and suitability for residual current measurements. (35 pages)

43. Outline of tests to determine the effect of extraneous currents on the intelligibility of telephone conversation. (8 pages)

44. Induction in the telephone circuits of the Santa Cruz-Watsonville exposure and in the test leads, from sources other than the 22,000-volt line. (12 pages)

45. Induction in the telephone circuits of the Santa Cruz-Watsonville exposure under commercial operating conditions, with the original transpositions in both power and telephone lines. (15 pages)

46. Supplementary to Technical Report No. 39. A study of additional transposition schemes for the Santa Cruz-Watsonville exposure. (14 pages)

47. Computation of the coefficients of induction for balanced and residual currents and voltages for the Santa Cruz-Watsonville exposure. (11 pages)

48. Experimental determination of coefficients of induction in the Santa Cruz-Watsonville exposure, with the original transpositions. (42 pages)

49. Further experimental determination of coefficients of induction for balanced voltages, in the Santa Cruz-Watsonville exposure, with the original transpositions. (13 pages)

50. Study of the influence of various transformer connections and flux densities on the third harmonic and its multiples in a three-phase circuit. (in preparation).

DISCUSSION ON "REPORT BY THE JOINT COMMITTEE ON INDUCTIVE INTERFERENCE", SPOKANE, WASH., SEPTEMBER 11, 1914.

P. N. Nunn: The paper just presented is one of signal interest and significance. It is of unusual moment in this, that it reports both an elaborate scientific study of great technical value and also a legal adjudication of conflicting interests between two public utilities of vast economic importance.

Briefly stated, the paper reproduces a certain report to the Railway Commission of the State of California, by a committee authorized by it to investigate the subject of electrical interference by other electrical circuits with "communication" service, including telephone, telegraph and railway signal. The investigation, occupying several years, assumed the character of a research into the intricate phenomena of distant electromagnetic induction, its remote origin in the characteristics and manipulation of power apparatus and its acoustic effects upon telephone service. To present the details of the various tests, methods and apparatus employed has involved the production of fifty special reports now summarized in this general report which draws a series of conclusions and submits and discusses a proposed code of rules for the prevention of the interference in question.

As a scientific research this investigation is invaluable and marks a distinct advance in applied electrical science. In view of the economic importance of telephone and similar service, and of the probable increase in the future in the capacities and voltages of power circuits, there appears a very real and difficult problem to be met in the evolution of the respective arts. To the solution of this problem such research should undoubtedly point the way. In this sense this report deserves marked appreciation. But at this time attention is called not so much to its scientific value as to the economic and legal effects of its code of rules.

Although recognizing a conflict of interests between the respective groups of electrical industries, the investigation was conducted and the rules drawn ostensibly to meet the problem only as a scientific question of demonstrable cause and effect. Unanimously indorsed by a committee purporting jointly to represent the telephone, the railway, and the electric power interests of the state, the rules purport to be, in effect, an agreement among all parties in interest, and as such, approved and adopted by the Commission, have become the law of California. By this process the Commission is led to adjudicate the differences and legislate changes in practise from scientific considerations alone, without regard to the broader aspects of the issues involved.

The problem is much broader than that. It involves another scientific aspect as well as questions of inherent rights, of equity, of evolution of the respective industries, and of the policy of the public toward its utilities. Moreover, the rules are not mere logical conclusions, and their full effect is not apparent from their text. Read casually, they imply a spirit of friendly cooperation toward some mutual purpose. In results, however, benefits accrue only to one interest, while burdens, even extreme hardships, are laid upon the other. Their full import appears only from careful consideration of each rule in the light of the whole seen from a mature point-of-view.

The partisan point-of-view from which these rules have been formulated is shown by their context. " Since these rules are designed for the protection of communication circuits," (Discussion of Rules, Art. IV) acknowledges that they are designed to restrain the power circuits. While the specific parties in conflict are somewhat obscured by including the railway interests as a third party and by use of the term " communication " instead of " telephone," yet Rule V in effect waives all conflict between railway and telephone interests, thus associating them and leaving the power interests alone under restraint. And while the caption " Historical," (first paragraph) in presenting the origin of this action styles it " the outgrowth of certain differences * * * * brought to the attention of the Railway Commission " instead of plainly " a complaint by the telephone lodged against the power interests," it likewise states (fifth paragraph) that this investigation, attributed to the Joint Committee, was in fact already a department of the Pacific Telephone & Telegraph Co. and of well-defined form and character before taken over by the Joint Committee, and also that it was continued (fourth paragraph) by a staff of telephone employees. It thus appears that this measure, instead of being a mutual matter or serving a mutual purpose, is in fact a telephone project from its inception to the conclusions which are formulated into the rules presented.

The specific rules, seventeen in number as grouped under caption II, may be classified as follows:

Mutual obligations respecting the spacing of power from telephone circuits; the uniformity of parallels, and the use of adequate systems of transpositions.

Specifications of power equipment, covering wave-form of generators, charging current of transformers, type and equipment of line switches, style and location of transpositions, and also requiring ammeters in grounded neutrals and the use of ground detectors

Dictation of methods in power distribution, covering balancing of loads, balancing of circuits, and methods of connecting and loading transformers.

Restrictions in operating procedure of power industries, covering line tests and the manipulation of automatics, operation with open circuits and grounds, measurements of ground currents and the charging of electrolytic arresters.

Stipulations respecting obscure power-circuit effects, requiring the limitation of residuals and the elimination of harmonics.

In discussing the individual rules, the following general considerations should be recognized.

The scope of the restrictions placed upon power interests is without tangible limit. Rule I prohibits "parallelism", which is defined as lines in such proximity "that the power circuit is liable to create inductive interference * * * *." Note the term "liable to." It is not "has" or "does" but "liable to." The question is one of degree, but no degree being even implied, the rule stands absolute. Since inductive effects are obscure and difficult of determination, the telephone interest may readily find occasion for claiming with some plausibility that almost any power circuit of the State is in parallelism to some slight degree. Where impracticable entirely to avoid parallelism, this rule makes the power circuit subject to the seventeen specific rules classified above.

For the enforcement of these rules, far-reaching power of reprisal and dictation is reserved by the telephone interest. Rule "d" successively stipulates, emphasizes, and confirms that the telephone interest "shall have the right to specify the number, type and location of transpositions" in power circuits.

Transpositions constitute the great general measure for neutralizing interference,—the last resort. They are both a hardship in expense and a menace to safety and service, and in degree both are, in general, proportional to the voltage transposed. The right to specify them, therefore, here becomes the weapon of the telephone interest against the power interests for all manner of possible shortcomings. Upon high-voltage lines and especially upon tower circuits in good telephone districts, this right carried to logical limits under these rules becomes tantamount to supreme authority. True, the telephone interest is limited as to the frequency of its use,—not oftener than one-sixth mile apart, but this very limit serves but to emphasize the length and breadth and depth of the power here grasped by the telephone interest.

None of the expense or burden of this new regime falls upon the telephone interest. Rule IV provides that "At the option of the (telephone) company * * * * any of the provisions of II and III may be waived." Since II and III comprise in effect the entire code, this provision becomes a blanket release giving the telephone interest immunity from any unwelcome involvement. Thus these rules which in effect "box" the power interests on all sides, notwithstanding their purport of co-operation, leave for the telephone interest a back door of escape always open. It thus, for instance, in paralleling a previous power circuit, could throw upon the power interest the hardship of reconstructing to conform to the rules, while itself evading through this back door any burden whatever.

Turning now to the seventeen individual rules as already classified, or rather to a few of their characteristic provisions; of those specifying characteristics of power equipment, rule

" p " requires power companies to obtain and use generators " giving, as nearly as reasonably possible, pure sine waves of voltage * * * *". Does this mean that the power companies of California are now using generators of characteristics inferior to those recognized as standard in the industry, or does it mean that electrical manufacturers must now evolve a line of generators of new design and characteristics for the special needs of California trade? Rule " q " raises a similar question as to the exciting current of transformers. Rule " j " prohibits the use of air switches which are now so generally used and from the further development of which so much is expected, while rule " h " requires the general use of oil switches " rendered automatic for short-circuits, grounds and abnormal neutral currents." This calls for a mechanism which has already been sought for many years but never yet produced and, in the opinion of many, beyond mechanical possibility.

Referring to the rules which restrict operating proecedure as now followed, rule " o " requires the charging of electrolytic arresters during the late night, while " m ", regarding line testing in cases of trouble, prohibits present prevailing practise and in effect requires the development of new methods and new apparatus for the localization of line faults.

Similarly, rule " n " specifying " * * * a record of hourly measurements of the neutral currents * * *," in effect seems to require a regular corps of attendants at every point of transformation employing a ground connection.

The class of rules respecting obscure phenomena incident to power circuits is less specific, yet rule " b " requires " special consideration shall be given to the prevention or elimination of harmonics * * *." This is a problem of many years' study by engineers, manufacturers and power companies alike, the solution of which might have saved from financial failure many of the power ventures of the past decade.

Without going further at this time into the many restrictions and their ultimate effects, the above characteristic cases will illustrate the radical nature of the rules, the impossibility of their fulfilment, and the length to which they go in demanding a virtual reconstruction of the power industries to meet the telephone's demands. They express the telephone interest's demand for impracticable ideals. That the results required are in fact impracticable ideals is tacitly recognized throughout the text by the constant recurrence of such evasive expressions as " Every reasonable effort to avoid," (several times repeated), " Every effort," and such vague expressions of degree as " Closely as practicable," " Nearly as practicable," " Most reasonable possible," and " Low as consistent with good practise."

The matter of the rule regarding crossings is of quite a different nature. Rule " a," after specifying the separation between power and communication lines, continues " The only exceptions to this provision * * * " are crossings, etc., which shall be

"* * * constructed in conformity with the National Electric Light Association specifications * * * *." The specifications here referred to were themselves initiated by the telephone interests of the East and presented through a committee formed under telephone influence. At best they are but proposed specifications, since, as a matter of record, the N. E. L. A. as an organization declined to adopt or sanction them. Since this matter occasioned much dispute, it has been generally understood that the question of crossings is specifically avoided in these rules as, in fact, it is, in title, headings and otherwise in the text. But nevertheless it is covered here and most effectively. Moreover, this brief incorporation of it seems to be without the full approval or knowledge of the Joint Committee, since at least one member still asserts that "These rules have nothing whatever to do with the question of crossings." In this light its interjection here seems somewhat a "joker" on the power interests. Suggestively similar are those terms which reserve to the telephone interest the power of waiving these rules as to itself and of specifying transpositions, and which in their final effects, as already discussed, are so far-reaching.

To briefly review: As seen by the power interests, these rules are radical, without tangible limit of scope, impossible of fulfillment, demand virtual reconstruction of their methods and business, and strain toward impracticable ideals; they have been framed by the telephone interest from an utterly partisan point of view, to secure to itself supreme power of enforcement; they have been carried to enactment against the power interests, many in number, competitive and without cooperative organization, by a single nation-wide monoply of vast coordinate resources, in California, as a first step toward similar rules wherever possible.

In conclusion: in the matter of electromagnetic interference there unquestionably is a very real and significant problem to be worked out theoretically by precisely such methods as those here reported. But then the same problem must again be worked out in practise through advance in apparatus and methods. Again the problem lies no more with the cause and its removal than with effects and their prevention; it embraces both. Moreover, by its very nature the problem primarily is that of the complainant, and its solution should first be sought at home. Thus there is force in the current retort of the power interests to the complaints of the telephone interest, that the latter has done as little to protect itself as the power interests have done to protect it. The final solution may be found as much or even more in the evolution of protective and corrective devices for telephone circuits as in the elimination of causes as attempted by these rules. It is quite possible that telephone circuits, being more sensitive, are now somewhat at the mercy of the less sensitive and more rugged power circuits and therefore should have some relief, but such a measure as this can but reverse the relation with far more hardship, while accomplishing nothing toward the final and equitable solution of the question.

A suitable code of rules, as scientific deductions reported to a scientific body or, accompanied by its natural counterpart in similar rules for the telephone industry, if adopted by this society, would be entirely proper and useful as a consensus of present opinion, subject to future advances. But these rules as law, inflexible to changing conditions and without such counterpart, are without equity or sense of proportion and contrary to economic order. Beyond the direct hardship imposed lies a greater wrong. Through their partisan point-of-view and narrow treatment of the issues, they establish by implication the principles of the power industry's legal liability for all possible effects of their circuits and of the telephone industry's fundamental right, wherever it may go, to an atmosphere free from magnetic influence, regardless of degree or priority of presence.

J. B. Fisken: I am sure a discussion of this paper, more especially of the rules, needs no apology before this body. I believe that rules or statutes should be discussed by engineering bodies when engineering is involved. Now, in anything I may say as to my opinions, I would simply state that I have been handling for a matter of twenty-eight years voltages varying from 90 to 60,000 and I have had quite a little experience. I want to refer to page 1446, under "definitions;" "a. Power Circuit," and "d. Line." These definitions provide for the inclusion in circuits which must be transposed, of arc circuits of voltages of 5,000 volts or more. But the rules do not state how they should be transposed. Series arc circuits are quite frequently run with one wire on a street; the return wire may be half a mile away. The people of California may have to string both sides of the circuit across this distance of a half mile to get a transposition, or build both sides of the circuit parallel to the telephone line.

I think there has been a mistake made in the arrangement of the rules; as, under Rule II, section "a," there is a rule which should be arranged under the heading of "Phantoms." A phantom, as I understand it, is something that has no apparent existence. As I regard this rule, and as Mr. Nunn has stated, it has nothing whatever to do with inductive interference; to my mind there is only one thing I can see it has to do with, and that is an imaginary physical hazard which does not exist.

A. H. Halloran: Since the earliest times an honest difference of opinion has always been an incentive to progress. Mr. Nunn evidently believes that this scientific investigation as to means for keeping a proper balance of power in circuits paralleling telephone lines, throws the balance of power too strongly in favor of the telephone company. Yet it should not be forgotten that the power companies have been the aggressors. Telephone circuits existed many years before there were power circuits. The telephone companies have spent thousands of dollars in vainly trying to solve the problem by compensating their own lines. Efforts were also made to adjust the matter legally, but it was recognized that the subject is primarily an engineering problem. Consequently, while it may be admitted that the burden of correction is now laid upon the power companies, their representatives on the committee have recognized that it is only by the true spirit of co-operation that any mutual understanding can ever be reached. The report is admittedly only preliminary, and the committee stands ready to make any adjustments or corrections which may be found necessary.

A. J. Bowie: I have been greatly interested in the report of the Committee on inductive interference, particularly as this deals with a field of investigation about which little has been written prior to the present time. Insofar as the findings of the report are based on actual tests and data, it furnishes a very interesting study.

The letter of transmittal states: "Therefore the rules are not put forth as being final or complete but must be regarded as provisional and subject to such change as the results of further investigation and experience may determine."

However, experience with which the committee is apparently not familiar has already demonstrated that their recommendations on switches and switching are based on a very unsubstantial foundation. Quoting from the "Discussion of Rules," on Rule II, h, i, j:

> The commonly recognized fact that oil switches produce less severe transient disturbances in power circuits, affords the basis for the provisions in the rules dealing with switches and switching.

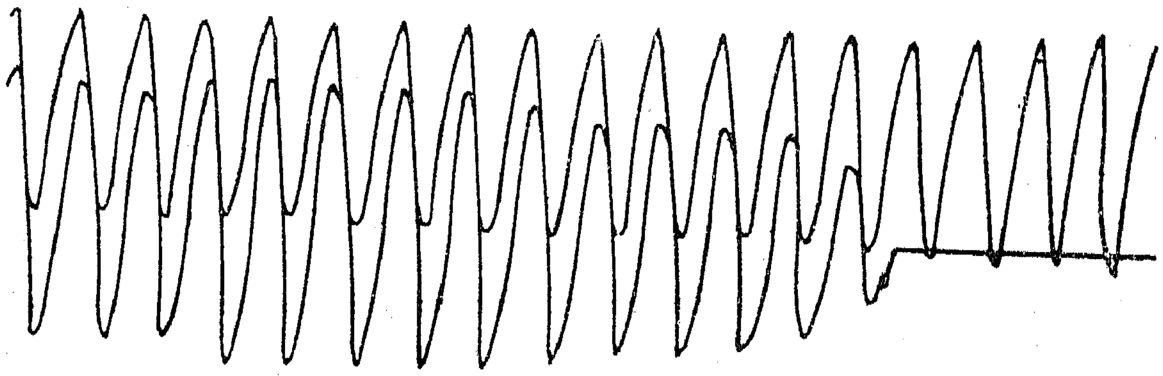
Quoting from the report itself, Section II, the following rules are laid down to govern switches:

> h—*Switch Equipment.* A power circuit involved in a parallel shall be equipped, between the source of supply and the parallel, with oil switches, all poles of which shall be mechanically interconnected for simultaneous action. With the exception of stations where an operator is constantly on duty, these switches shall be rendered automatic for short-circuits, grounds, and abnormal neutral currents.
>
> i—*Switching.* All switching on all parts of a system connected to a circuit involved in a parallel, which causes harmful transient disturbances in communication circuits, shall be done by means of oil switches, all poles of which are mechanically interconnected for simultaneous operation.
>
> j—*Use of Air Switches.* The use of air switches, on a power circuit involved in a parallel, is prohibited except for purposes of isolating sections of dead line, or for disconnecting transformers under no load. This applies to the entire power system, any circuit of which is involved in a parallel, unless such switching is so remote as not to cause harmful transient disturbances in the communication circuits.

One of the important expenses in the transmission and distribution of power is the cost of high-tension switches. Air switches represent a very material saving to the consumer over the cost of oil switches, as their prices will range from about one-third to two-thirds of the cost of the latter for switches of equal capacity. In addition thereto, air switches effect a still more important saving for high-tension work in that they may be located out-of-doors, whereas the housing of oil switches in many cases costs as much or more than the switch itself. Therefore the use of air-break switches will effect a material saving to the power companies and hence no rulings of any nature should be passed to forbid this saving unless the air-break switches produce an extremely bad and undesirable effect which will more than offset the great saving from the use of this type of switch. Hence it is with great astonishment that I note the report in this respect does not pretend to be based on scientific tests but on what is termed a "commonly recognized fact." At one time it was a commonly recognized fact that the world was flat and the universe revolved around it. It is unfortunately the case in engineering, as in other matters, that theories based on insufficient data obtain partial credence and are accepted without real investigation.

By the use of expensive and complicated apparatus it is possible to establish a very short arc in air in an exceedingly strong magnetic field and to make the arc so established set up high-frequency oscillations. But to accomplish this result requires the use of special apparatus entirely foreign to that used in any air switch construction. It is quite possible that an arc produced under oil might under similar circumstances become oscillatory when sufficient attention is paid to the details of construction to accomplish this result. As it is possible to produce an oscillatory effect in air many engineers without investigation have sincerely believed that the operation of air switches would cause a high-frequency surge, and this has resulted in a certain amount of prejudice against the use of air-break switches.

An interesting article has just appeared in the *General Electric Review* of September, 1914, by Mr. W. P. Hammond, Engineer of the Northern Contracting Company, giving a description of extensive tests on air-break and oil switches, conducted on systems of 44,000 and 110,000 volts, opening loads of several thousand kilovolt-amperes. These tests fully demonstrate the fact that in many respects the air switches are superior to oil switches. Quoting from the article: "In order to get a general check on the voltage surge, set up on the load side on opening the circuit with an air-break switch, a needle point spark gap was connected to two of the phases, set accurately for different voltages, and the maximum sparking gap noted for each switch under the same load conditions. The same experiment was tried on an oil-break switch in the circuit and the maximum sparking distance recorded when the circuit was opened with this switch was greater than with the air-break switch." This shows that oil switches cause a greater surge and rise of voltage than air switches. The article further states "The oscillograph records obtained during these tests do not indicate that there is any high frequency set up on the lines by air switches which is especially dangerous to the equipment." Also, "The spark gap test previously referred to in this article would indicate that the surges in the voltage set up by the air-break switch are not so violent as those set up by an oil switch, although this is not in line with the current opinion." Also, "The general conclusion drawn from these tests is that the air-break switch will doubtless replace the oil switches for many uses." Thus it is apparent that the air-break switches do not set up material oscillations in the circuit. The illustration herewith, from the above-mentioned article, is an oscillograph record showing the conditions when opening a 50,000-volt system and interrupting an energy load of 2500 kv-a. with an air-break switch. The upper curve represents the voltage on the supply system, and the lower curve represents the current. It is of particular interest to note that the current curve tapers off gradually, the time of tapering consuming about six cycles. This is a very important consideration in the action of air-break switches, showing that the introduction of the high resistance of the long arc cuts down the current before the moment of final break, thus lessening the voltage rise over that which occurs with an oil switch, where the break is more sudden. The time of operation of air switches is in general from one to three seconds, provided the switch is not overloaded. The actual time will, of course, depend on the design of the switch, as well as on wind conditions. The time given above is a result of a long series of observations.



Showing Interruption of an Energy Load of 2500 kv-a. with an Air-Break Switch

The conditions of opening of an air switch are commonly misunderstood. A short arc in an air switch will be of relatively little resistance so that until the arc lengthens materially, there will be no substantial change in the current conditions over those obtaining prior to the opening of the switch. After the arc has lengthened sufficiently, an effective gradual decrease in the current will occur and will require only a few cycles. Thus, for illustration, if it took the switch in question three seconds from the time of opening the switch until the arc was extinguished, this would last over a period of 180 cycles. During the first 174 cycles, no very material change would take place in the conditions of operation over what existed prior to opening the switch. During the last six cycles, the resistance of the arc increases rapidly, thus gradually diminishing the current up to the point of final break. At worst, even if the switch operation does affect the telephone lines, the period of such operation is exceedingly brief, also, the switch operation is in general very infrequent on high-tension lines, so that even if severe disturbances should be produced, the total time during which the telephone service would be affected in a year would be so small as to be practically negligible in comparison to the saving to the companies and consequent saving in the cost of power delivered to the consumer.

From the foregoing the following conclusions are drawn:

1. Air-break switches will produce less rise of voltage than oil-break switches, and hence will not affect the telephone system as severely as the oil switches.
2. No material high-frequency surges are set up on the opening of air switches.
3. The duration of opening of air switches is somewhat longer than that of oil switches but the total time of such operation is so small as to be negligible in its effect on the telephone service.
4. The advantages of air switches are very much greater than any disadvantages cited.

I might add further that air-break switches are in use for controlling many important lines, among others, the longest line in the world, comprising the system of the Southern Sierras Power Company, which transmits power from Bishop to San Bernardino, a distance of 240 miles. Also, I have installed many air-break synchronizing high-tension circuit breakers for synchronizing high-tension lines, and according to all reports received the operation in synchronizing is perfect, and does not cause the slightest appreciable disturbances of the system.

I am sure that everyone will agree in the suggestion that before drastic rulings on switching are adopted by any commission, more complete investigations should be made as a basis, rather than the unsubstantial basis of "commonly recognized fact."

George S. Humphrey: Referring to the paragraph entitled "Minimum horizontal separation," I question whether the last three lines of that really mean very much. It says that crossings shall be "constructed in conformity with the National Electric Light Association's specifications for overhead crossings or other approved equivalent which may be agreed to by both companies." As most of you are probably aware, there was a resolution passed on this subject at the last meeting of the National Electric Light Association. This resolution reads as follows:

> Whereas, at the annual convention of the National Electric Light Association in the year 1911 there was presented a report by the Com-

mittee on Overhead-Line Construction, to which the Executive Committee then gave its qualified approval, since which time the progress in the state of the art and the continued good work done by the Committee have developed recommendations of better practice which the overhead-line-construction committee now presents to this convention;

Therefore, be it RESOLVED, That the thanks of the Association are due and extended to the Overhead-Line Construction Committee for its sacrificing and painstaking efforts, and, in view of the later recommendations of that Committee, that the heretofore qualified approval of the 1911 report is hereby rescinded, and that the question of voltage limitation shall be eliminated from any recommendations or reports of any committee of this Association, by inference or otherwise, with relation to overhead-line construction practices, and that any such recommendations or specifications to this or previous conventions by any committee shall not be sanctioned by this Association.

This resolution was adopted by the National Electric Light Association in June, and so at the time these rules were prescribed by the Commission, there was not and is not now any such thing as "National Electric Light Association's Specifications for Overhead Crossings." No such specifications are included in the Handbook on Overhead-Line Construction, which was published at that time.

It appears that in defining telephone circuits, telephone systems of high-tension operating companies are included as a telephone circuit. The term includes any metallic telephone circuit operated by any railroad or other company for dispatching purposes. I just wondered if private telephone systems of transmission companies are included in that definition of the telephone circuit.

In the section of the country with which I am familiar there were formerly two telephone systems, and they have lately been consolidated. Now almost every important road in the country has a telephone line on each side of the road which is owned by the same company. I wonder what the recommendation of the Committee would be as to where the line of the power company should be placed along these roads.

J. C. Martin: I think Mr. Nunn has covered the practical aspects of the question about as well as it can be done. However, from the standpoint of the experience that I have had in connection with transmission and distribution problems in the Northwest, I have a few suggestions to make.

The 5000-volt limitation is particularly bad. The company that I am connected with operates a great many miles of 6600-volt circuit. So far as any records we have, or anything that we have heard from the telephone companies, show, we have no trouble due to inductive interference with properly constructed telephone lines. These rules would practically put us out of business as far as the 6600-volt line construction and operation is concerned. That is especially true because of the rule covering transformer connections. Owing to the conditions we have to meet we make very frequent use of the open-delta connection and do not operate any of our single-phase transformers without grounding the secondary neutral.

On the question of telephone lines occupying both sides of the road: I think here in the Northwest, and I believe in most portions of the country as well as the Northwest, you will find that every country road has at least one telephone line that usually succeeds in occupying both sides of the road, and often there are two or more lines that stagger from one side of the road to the other. The lines are ordinarily ground return circuits and the construction adopted is usually the very cheapest that can possibly be used and have the lines stand at all, and no effort is made to even install the ordinary telephone protections. I am wondering, with Mr. Humphrey, what would happen in case a power company desires to build a line of over 5000 volts along such a country road, either in the State of California or wherever these roads might be located, and these rules enforced. The power company could undoubtedly be forced to rebuild such lines completely if these rules were in force. It seems to me absolutely unjust to force the power companies to stand the trouble that is due in many cases entirely to the poor construction of the telephone lines involved.

Like Mr. Nunn, it appears to me, from the wording of these rules, that a large number of important questions of design are left to the sanction and fiat of the telephone company; in other words, the engineers of the power companies are without any voice whatever in the matter as to how their service shall be handled or as to the methods or designs they shall adopt to best serve their customers. I know that in the territory we are serving the burden put upon the company in complying with rules of this sort would practically prohibit the serving of a large number of our customers and prospective customers.

Again, the telephone companies are relieved of practically all responsibility in the matter and the power companies are saddled with the responsibility and expense of avoiding any trouble that it may be necessary to take care of. I believe it will be conceded that the power companies furnish service that is as much of a public necessity as that furnished by the telephone companies. If any action is to be taken, the responsibility of caring for the trouble should be divided equally between the parties involved, and the telephone companies as a whole should be forced to a standard of construction that will be at least equal to that maintained by the power companies.

L. J. Corbett: Entirely apart from the legal aspect of this report, I think that we are fortunate in having it before us for its value as a technical contribution. It represents the investigations of a committee which was well equipped; it presents some of its findings, and contains certain recommendations which do indicate to us how we may avoid interference.

There is one thing that attracted my attention at first glance at the paper, and that is in one or two of the definitions, the use of the term "residual." Possibly most of you would not take up such a point as this, but at first glance I wondered which meaning of "residual" was intended. I find that it refers to "the vector sum of the current in the several conductors of a power circuit." We are used to thinking of residual as something left over, a residual charge upon a condenser, residual magnetism in a field, and it seems to me we are using an old word for a new idea, which new idea requires a separate definition for the old word. It does not give us the idea at once as to what is meant, and I wonder if this committee gave any great thought to this matter in drawing up their definitions. It would seem that a word could be found which would connote the idea a little better than this word residual.

In reference to Mr. Fisken's question about the series circuit, I would offer as a suggestion that in such a case, according to this definition of residual, the entire current of the series system would be residual current and the entire voltage, the residual voltage.

Charles P. Kahler: In the discussion of Rule V the following comment is made:

> *V.* The Committee has undertaken no investigation of cases of parallelism with alternating-current railways, but as the seriousness of this class of exposure is recognized, it was thought desirable that it be referred to specifically.

However, although the Committee admits that it has made no investigation upon which to base any regulations for such conditions, nevertheless, it has undertaken to make such regulations, as shown by the following portion of Rule V.

> In the present state of the art, no means for completely overcoming inductive interference from such parallels is known, hence, they are to be avoided if possible.

If such rules were in force in the State of Washington, could the Inland Empire System be extended if there was a telephone or power line in the territory where it is proposed to extend it? It is well known that considerable study has been made to eliminate disturbances caused by both alternating- and direct-current railway circuits, and the latest work and information on this subject would indicate that trouble from this source may be overcome. The fact that the railroad companies themselves have to maintain communication circuits makes it necessary to provide means to prevent interference with them. It does not appear to me proper to add rules which may cause unnecessary expense to any electrification proposition unless the effect of such rules is definitely known.

L. T. Merwin: I was greatly pleased with Mr. Nunn's calm, judicial manner in opening the discussion and with the nature of his remarks from the standpoint of a power man. Mr. Nunn, I think, has gone right to the quick of the matter from the standpoint of the power man, and "forewarned is forearmed." This thing has been done in California; most of you gentlemen are from northern states, northwestern states; if such a thing as this is to be put in a legal form in Oregon or Washington or Idaho or Montana I am sure there will be before the respective commissions of these states very well prepared and vigorous opposition, and rightly so, I believe.

I have great admiration for this paper as a scientific document; it puts before us in a very lucid way some things that we all wanted to know, but it puts them also firmly before us in a positive legal way, not bringing out what we may do, but, "Gentlemen, how do you like this? This is what you have to do." It is written by a body of men of undoubted scientific attainments and is presented to us as their findings, but presented as their findings after those findings have been put into legal form. It isn't here for our discussion as to the merits of the thing from an engineering standpoint, it comes as an absolutely closed book, and I feel very sorry for the power companies operating in California.

Mr. Humphrey brings up the point as to what will happen in a legal way, or how is one to interpret the situation, if the communication company is also the power company, considering its own communication lines. Mr. Nunn very clearly stated what could be done: The power company can simply sneak away from itself out of that "back door." That is all right and is easy.

We have a line of our own; I have been troubled with induction on that line for some seventeen months. On about fifty miles of our power line we had considerable difficulty owing to the topography of the country. It passes down along the north bank of the Columbia gorge. I have found it absolutely impossible, try as I may, up to the present time to neutralize the inductive effects on the telephone line. The power line is not transposed. However, we have done something else than transposing, and it seems to me that the telephone company might do the same. I have simply given up all efforts to get rid of induction, I have accepted it as a fact, and then looked around to see if I could kill it or get rid of it insofar as the receiver of the telephone instrument was concerned, and I believe that I have succeeded. Now if a power company can succeed surely the minor disturbances that arise on the telephone lines can be taken care of by the telephone companies. It seems that those slight residual effects—I mean residual not in the sense in the paper—can still be neutralized. Very briefly, and as an aid to others who are having the same trouble, I have learned through the manager of the Federal Wireless Telephone Company in Portland of a high-power transmitting instrument made by some private firm in Seattle, the name of which I shall be glad to give to any one. I have arranged reactors and condensers into a resonant circuit at the instrument, and found I could actually neutralize the inductive effects of the power line at the instrument. With an ordinary transmitter the working current is not strong enough to force through the series impedance of this arrangement. By using this high-power telephone transmitter I found I could get sufficient amplitude of talking current. I simply mention this as a possible relief to other power men who have had the same trouble with their own telephone lines.

C. E. Rogers (by letter): This report is very interesting as it covers a subject to which much space in the scientific press has been devoted in a qualitative manner, but, like previous papers, it does not give any quantitative results. I realize that many more formulas are yet to be derived in order to present this subject with mathematical accuracy, such as has been done in the calculation of corona losses, and I regret that at least one appendix has not been devoted to the calculation of the voltage and current induced in the communication circuits of one of the exposures mentioned. In order to present the rules that have been recommended, these data must have been accumulated, and an appendix containing quantitative information would receive deserved attention and valuable criticism.

A. J. Bowie, Jr. (by letter): Supplementing my oral discussion of the report of the inductive interference committee, the most direct and authoritative evidence on results of opening air switches can naturally be obtained from companies making extensive use of apparatus of this nature. Consequently for further investigation of this subject, I have written to The Pacific Power Company, Bodie, California, and The Southern Sierras Power Company, Riverside, California, both of which companies employ air switches, almost exclusively, for their high-tension systems.

I have addressed the following questions to these companies:

(1) Have you on your lines any material length of what may be termed parallel to the communication circuits?

(2) To what company do the communication circuits belong?

(3) Has your company ever received complaints from owners of communication circuits about the inductive effect of your power lines?

(4) Have any specific complaints ever been received of trouble in communication circuits from switch operation?

(5) If so, what is the general nature of such complaints, *i.e.*, as affecting the interference with communication or as affecting any safety or any other apparatus connected to their system?

In reply thereto, I have received the following answer from Mr. C. O. Poole, Chief Engineer, Southern Sierras Power Company:

(1) We have several cases that might be used under the term parallel to the communication circuits.

(2) The communication circuits belong to The Pacific Telephone &

Telegraph Co., the Southwestern Telegraph Co. and The Western Union Telegraph Company.

(3) We have received several complaints from the Pacific Telephone & Telegraph Co., Southwestern Telegraph Co., and the Interstate Telegraph Co., of the inductive interference with their communication circuits.

(4) We have not received any specific complaints of disturbances caused by the operation of air switches. We have, however, received complaint from the disturbances of the service caused by the charging of the electrolytic lightning arresters. We are preparing to install current-limiting resistors which will probably reduce the cause for complaint.

Reply from Mr. W. N. Chatfield, General Manager, The Pacific Power Company:

(1) Telephone lines parallel our transmission line for a distance of 125 miles, and are on the same poles as the transmission line for a distance of 66 miles.

(2) Telephone lines used in connection with power operation and not for public use.

(3) We have received no complaints on account of inductive effects on the telephone lines. Naturally there is a good deal of induction on the telephone line but not so that it interferes in any way with the operation of same, and as the line is for our own use, naturally no one has any complaint to make.

(4-5) We have not had any trouble to amount to anything in our telephone system caused by switch operation on the transmission line.

It is greatly to be regretted in making this investigation, that the committee did not avail itself of the experiences of some of the largest users of air switches on the Pacific Coast. Had it done so, I feel sure its report on this subject would have taken a very different aspect.

All the evidence available, shows very strongly that oil switches will produce more severe disturbances than air switches on their own, as well as on neighboring lines. There is one feature of the report which is most inconsistent, namely, the prohibition of air switches, and at the same time the allowance of the use of electrolytic lightning arresters. From the very nature of the electrolytic arrester, the breaking of the current either when the arrester is being charged, or when the arrester is operating, is very abrupt, and hence very apt to cause undesirable effects on parallel lines. To be at all consistent, the electrolytic arrester should have been included in the general prohibition of the subject of arcs in air.

Even though oil switches will cause more severe disturbances than air switches, there is certainly no reason sufficiently strong, at the present time, to render advisable in any way the prohibition of any special type of switch, and legislation in this direction is a definite step backwards.

Joint Committee on Inductive Interference: The above discussion of the report of this Committee discloses many misunderstandings, some of the clear meaning of the recommendations, but mainly of the scope and the spirit of the Committee's work. This scope and spirit may perhaps be best expressed in words as follows:

The State of California must have both electric power and electric communication. The former now conflicts with the latter and the conflict is becoming more serious year by year as the two services expand. When the two services approach their ultimate development of universal power distribution on the one hand and universal communication on the other hand, the conflict will greatly hamper the communication service if the power service is permitted to expand with no limitation of its inductive effects. The greatest good to the greatest number, which is in this case the best and cheapest power service combined with the best and cheapest telephone service to the people of the State, will be obtained by the imposition of such burdens on the power service as will result in improvements to the telephone service greater than the burdens imposed. The Committee contends that each of the burdens imposed on the power service by the rules recommended will result in an improvement of the telephone service to the citizens of the commonwealth totally out of proportion to the interference of those same rules with power service to the citizens of the commonwealth. This view has been kept clearly in mind in the formulation of each ruling recommended to the State Railroad Commission.

The Committee admits that "benefits accrue only to one interest while burdens are laid upon the other." Since by no stretch of the imagination can the inductive effects of communication circuits as now operated (wireless excepted) be considered as interfering with power circuits, the latter will not be benefited. No engineer should intimate that such a benefit should be sought. The Committee does not admit, however, that the burdens are "extreme hardships," but contends that these burdens will in all cases do more good than harm to the public services of the State as a whole.

Admittedly, "the Commission is led to adjudicate the differences and legislate changes in practise from scientific considerations alone * * * *" and all praise is due the Commission for this action. But the Committee submits that there the "broader aspects of the issues involved," viz., equity, inherent rights, the evolution of the respective industries, and the policy of the public toward its utilities, are all covered by or are subordinate to the principle of the greatest good to the greatest number. This has been the chief consideration followed throughout.

The Committee does not agree that the rules "establish by implication the principle of the power industry's legal liability for all possible effects of their circuits," but does contend that they establish in California the power industry's legal liability for unnecessary, unwarranted or avoidable inductive effects where such effects will work hardships materially greater than those necessary to avoid them. Neither do the rules establish "the telephone industry's fundamental right, wherever it may go, to an atmosphere free from magnetic influence, regardless of degree or priority of presence." They do establish the telephone industry's fundamental right, wherever it may have metallic interexchange circuits (not subscribers' circuits), to an atmosphere free from inductive influences so great as to cause harm more serious than the burdens imposed on the power industry by reducing such influence.

The Committee admits the justice of the criticism (favorable or unfavorable) that "the scope of the restrictions placed upon power interests is without tangible limit." The absolute impossibility of determining in the general case, for example, to just what extent the residual current in a power circuit can be reduced with a burden on the power system less than the benefit to the telephone system, makes it necessary to use the expressions criticised, "closely as practicable", "every reasonable effort", "low as consistent with good practise," etc.; unfortunately, perhaps, the communication interest is the party best able to judge the effects of these intangible quantities and this interest has been given in some cases the right within fixed limits to specify quantities, on the assumption of co-operation, with the Commission as a court in case of disagreement. The Committee hopes that its future work will make it possible to be more explicit with respect to such quantities as are capable of quantitative analysis into burdens and benefits.

The Committee admits also that the communication interests have much of their future life to gain and nothing to lose by the investigation and its results, and that the power interests have nothing to gain and little to lose as compared to the gains of the other party; for which reason the telephone interests have contributed to the work more men, funds and equipment than have the power interests, and have naturally taken a deeper interest in the work. Admittedly also, the telephone interests of practically the whole country have been pitted against the power interests of California, which in this work were not "competitive and without cooperative organization." But the Committee denies that the natural zeal set up by this greater incentive has been effective in making its recommendations depart from the principle of the greatest good to the greatest number.

A more nearly just criticism is that "the problem lies no more with the cause and its removal than with effects and their prevention," but the Committee has not yet found many opportunities for improvement of telephone plant or operation because the telephone interests have already made many such improvements.

It is not true that "none of the expense or burden of this new regime falls upon the telephone interest." The rules recommended cover retransposition of the telephone lines to match power line transpositions, which is no small requirement, since many telephone transposition points are required for each power transposition, and with a heavy telephone lead there must be a large number of transpositions at each transposition point. It is hoped that the future work of the Committee may develop other possibilities of improvement of the telephone plant.

The more specific criticisms of details of the report are subject to the following comments:

The requirement of wave shape of synchronous machinery does not mean that the power companies of California are now using generators of inferior characteristics, nor does it mean that "electrical manufacturers must now evolve a line of generators of new design and characteristics for the special needs of California trade." It does mean that due weight should in the future be given the matter of wave form from the standpoint of its possible inductive effect on other circuits. There is nothing extreme contemplated. The Standardization Rules of the Institute are set up as the limiting requirements.

With regard to the exciting current of transformers, investigation will show that the 10 per cent limitation covers all ordinary practise and good design, but excludes densities so excessive that they might be considered "freaks."

The requirement of oil switches rendered automatic for abnormal neutral currents, far from being beyond mechanical possibility, calls only for the addition of the most simple kind of an overload trip connected in a circuit of ground potential.

The rule regarding line testing in case of trouble does not "prohibit present prevailing practise" as far as California is concerned, and does not "require the development of new methods and new apparatus for the localization of line faults," but does enforce the best prevailing California practise, without new methods or apparatus.

The record of hourly measurements of neutral currents is called for only at the main generating and substations, at most, if not all of which, operators are on duty at all times, for which reason this rule does not "in effect seem to require a regular corps of attendants at every point of transformation employing a ground connection."

Harmonics of either voltage or current in a power system, far from being "a problem of many years study by engineers, manufacturers and power companies alike, the solution of which might have saved from financial failure many of the power ventures of the past decade," are usually inappreciable so far as the operation of the power system itself is concerned, and in the few extreme cases where they are so appreciable, they can be reduced without material expense.

The only rule affecting construction at points of close proximity is not outside the scope of the Committee's work, as an examination of that part of the report covering the formation of this committee would show that the Railroad Commission called for recommendations "tending to minimize inductive interference *and physical hazard* arising from parallelism of different classes of circuits."

The specifications referred to as those of the N. E. L. A. are well known in California as those embodied in the joint report of the Committee on overhead line construction of the N. E. L. A., the High-Tension Transmission Committee of the A. I. E. E., the committee on power distribution of the A. E. R. A., and other committees, and were referred to by the above abbreviated name since the same name is used by the Railroad Commission of the State of California in its General Order No. 26 covering overhead crossings.

Series arc circuits are not constant potential in character and are therefore excluded from the rules under the definition of power circuits.

The criticism referring to roads with telephone lines on both sides is generally inapplicable, as most such duplication is of subscribers' circuits, which are excluded.

Some other criticism might be similarly shown to be due to a lack of care in reading the report or of familiarity with the subject.

The criticism of the ruling on the use of air switches has been based on an entire misinterpretation of the spirit of the work. The Committee stated that the reason for this ruling was the commonly recognized fact that oil switches produce less severe transient disturbances in power circuits. While this may not be true so far as voltage rise in the power circuits is concerned, the disturbances which affect by induction neighboring communication circuits are far more severe when air switches are used than when oil switches are used. The disturbance of a power circuit due to switching that causes the greatest inductive interference is the breaking of one or two phases in advance of the other two or one phase. In case of a system with neutral grounds this action gives a large momentary ground return current in the power circuit. In case of an isolated system this action gives momentary application of full line voltage to only one or two conductors, with no balancing voltage on the other conductor or conductors. Either result causes inductive effects excessive as compared with normal operation. A properly constructed oil switch gives more nearly simultaneous interruptions in all poles, hence this inductive effect is of shorter duration. The published data on which this ruling has been criticised give the following information on this point:

> The maximum time necessary in which to interrupt the arc in any of the 50,000-volt tests was 25 seconds and the minimum 2 seconds, the average time for a large number of the tests being 6 seconds. The average time necessary to interrupt the arcs in the 110,000-volt test was 7 seconds, the maximum being 16 and the minimum 3. This means that the air-break switch requires anywhere from 120 to 1500 cycles in which to interrupt a circuit, while the oil switch may accomplish this result in half a cycle. (*General Electric Review*, Sept. 1914, page 868).

Other tests on oil switches show breaking of all three phases within a small fraction of a cycle. With air switching requiring several hundred cycles to break the circuit, the instant of breaking of each phase depends upon atmospheric conditions, and the three breaks are separated by far longer time intervals than those of oil switches. The excessive residual currents and voltages during these time intervals give inductive effects commonly described by the telephone colloquialism "a bat in the ear." The Committee has records of many cases of temporary injury to hearing, both from air switching, and from the use of oil switches not properly interconnected for simultaneous action. Members of the Committee represent by far the largest users of both air and oil switches on the Pacific Coast and also represent interests having by far the largest number of parallels existing in California, if not in the world. The experience of the interests represented amply confirms the scientific bases for these rulings.

A. H. Babcock (by letter): If the minutes of the meeting at which the Joint Committee was organized could have been published with the report, certain criticisms, perhaps, would have been worded differently. The minutes are too lengthy for publication, even in abstract, but the history of the organization of the committee as recorded therein is now given to show the reasons for the investigation, the spirit in which it was undertaken and prosecuted, and the representative character of the members of the committee.

Several complaints had been made to the Railroad Commission by the Pacific Telephone & Telegraph Company, against inductive interferences by certain power companies' circuits. Tests to determine causes and remedies had been carried on for two months by the companies involved, working with the authority of the Railroad Commission Engineering Department. The results promised so much that, at the request of the chief engineer of the Railroad Commission, a general meeting was called "between representatives of various telephone, telegraph and power companies of California, and representatives of the Railroad Commission of the State of California, for the purpose of appointing a committee to conduct tests and gather information with reference to induction matters, both applying to cases now before the commission, and generally throughout the State." (Minutes).

Invitations to appear at the meeting were sent to every telephone, telegraph and power company operating within the State. Twenty-three companies responded by representative appearances. After a preliminary discussion the Railroad Commission requested all the power men to meet in one room, all the telephone and telegraph men to meet in another room, the two groups each to name four men to serve on the committee, (subject to the approval of the commission), with four members of its engineering department staff, and one from the railway interests, not included with either of the two groups in adverse interest, because the railways operate both power and communication circuits.

The president of the Railroad Commission in opening the meeting above mentioned said, "It is distinctly understood on behalf of the commission that we desire to have this committee appointed representing the power companies and the telephone and telegraph companies and this commission, and that of course the recommendations of this committee will be very persuasive on the commission, but * * * * the commission will formulate the rules we * * * * believe we can get permanent results that will help us in the future on these matters of construction, and we desire it understood specifically that it is to be carried on not exactly under the direction but under the supervision of the commission with a view of a recommendation to this commission."

The personnel of the committee selected is given below.

Representing Railroad Commission:
- Mr. R. A. Thompson, Chief Engineer.
- Mr. A. R. Kelley, Assistant Engineer.
- Mr. James T. Shaw, Assistant Rate Expert.
- Mr. R. Emerson Hoar, Assistant Rate Expert.

Representing Railroad Interests:
- Mr. A. H. Babcock, Consulting Electrical Engineer, Southern Pacific Company.

Representing Telephone and Telegraph Interests:
- Mr. A. H. Griswold, Plant Engineer, The Pacific Telephone and Telegraph Company.
- Mr. R. W. Gray, Division Superintendent, Western Union Telegraph Company.
- Mr. C. H. Temple, General Manager, United States Long Distance Telephone Company.
- Mr. L. M. Ellis, General Manager, Union Home Telephone Company.

Representing Power Interests:
- Mr. H. A. Barre, Electrical Engineer, Pacific Light and Power Corporation.
- Mr. Louis Elliott, Engineer, Great Western Power Company.
- Mr. P. M. Downing, Engineer, Pacific Gas and Electric Company.
- Mr. J. E. Woodbridge, Chief Engineer, Sierra and San Francisco Power Company.

The organization and personnel of the Joint Committee on Inductive Interference were approved by the Railroad Commission on January 6, 1913, and the committee thereupon proceeded with the necessary tests and investigations.

Since the formation of the committee, through additions, resignation or death, the personnel of the committee has changed as follows:

Mr. Louis Elliott resigned and Mr. J. A. Koontz, Engineer of the Great Western Power Company, was appointed in his place.

Mr. V. V. Stevenson, Electrical Engineer of the Postal Telegraph Cable Company, and Mr. L. N. Peart, General Superintendent of the San Joaquin Light and Power Company, were added to the original membership by action of the committee.

Mr. R. A. Thompson, Chairman of the Joint Committee, resigned. Mr. W. C. Earle, his successor as Chief Engineer of the Commission, was elected to membership and chairmanship. Subsequently Mr. Earle resigned and Mr. Richard Sachse, then Acting Chief Engineer, now Chief Engineer of the Railroad Commission, was elected to membership and chairmanship.

Mr. L. M. Ellis resigned and Mr. R. W. Mastick, Transmission and Protection Engineer of The Pacific Telephone and Telegraph Company, was elected to membership.

Mr. H. S. Warren, Electrical Engineer of the American Telephone and Telegraph Company, was elected to honorary membership.

Mr. James T. Shaw, Secretary of the Joint Committee, resigned. Mr. A. R. Kelley was elected to the office of secretary. The vacancy in membership created by the resignation of Mr. Shaw was later filled by the election of Mr. A. L. Wilson, Assistant Rate Expert of the Railroad Commission. Mr. James T. Shaw was elected to honorary membership.

The death of Mr. L. N. Peart created a vacancy in membership which was filled by the election of Mr. J. P. Jollyman, Engineer of Electrical Construction of the Pacific Gas and Electric Company.

Mr. A. R. Kelley resigned and the vacancy was filled by Mr. A. F. Bridge, Assistant Electrical Engineer of the Railroad Commission.

The Chief Engineer of the Railroad Commission always has been Chairman of the Committee.

The power companies whose officers are named above are the ranking companies of this State, in respect to age, extent of system, and magnitude of interests involved. In at least these respects they may be compared with any other similar interests elsewhere. Their representatives have carried out the investigation in a spirit of non-partisan scientific search for the facts, and for the remedy of a condition, in a fashion that repeatedly has aroused the whole-hearted admiration of the other members of the committee.

The report represents the best efforts of those who signed it. Every sentence was studied carefully. Not one was passed for final copy until every member had been given full opportunity to present his views, and often, the final vote was not polled until certain members were satisfied that every man present understood the full effect of the vote on both sides of the question. In every case the vote was unanimous.

Presented at the 299*th meeting of the American Institute of Electrical Engineers, New York, October* 9, 1914.

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PROTECTIVE REACTORS FOR FEEDER CIRCUITS OF LARGE CITY POWER SYSTEMS

BY JAMES LYMAN, LESLIE L. PERRY, AND A. M. ROSSMAN

ABSTRACT OF PAPER

This paper outlines the use and limitations of protective reactance coils in feeder circuits. When no feeder reactors are used, doubling up the station capacity increases the number and severity of short circuits. The insertion of feeder reactors cuts down the severity of a short circuit and practically renders the effect local, so that beyond a certain point additional generator capacity does not appreciably increase the severity.

Curves are given showing what the effects of feeder reactors are, with and without bus reactors, for generators of various reactances. The advantages that might be gained by parallel operation of feeders are discussed and the difficulties to be encountered are pointed out.

INTRODUCTION

IN a paper entitled "Protective Reactance in Large Power Stations" presented at the 1914 midwinter convention of the Institute, the authors discussed the use and limitations of current limiting reactors in generator circuits and in power station busbars.

It was shown in that paper* that, on a radial feeder system, the use of busbar reactors tends to confine the disturbances from a short-circuited feeder to that section of the busbars to which the feeder is connected. It was also shown, in one example, that the use of 3 per cent feeder reactors reduced the amount of current flow into a feeder short circuit to 1/4 of what it would be without feeder reactors.

It is the purpose of this paper to discuss, in greater detail, the use and limitations of reactors in the feeder circuits of large city power stations.

The methods of deriving the curves of this paper are the same as are given in the appendix to our earlier paper. Where reference is made to maximum values this refers to maximum r.m.s. values and not to maximum instantaneous values.

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*See Part I, this volume, p. 23.

Transient effects are not taken into account by these curves. The transient effects can be derived from the r. m. s. values.

THE NEED OF FEEDER REACTANCES

Consider the case of a 225,000-kv-a. power station which generates electricity at 11,000 volts. Such a station would have, say, 80 feeders each rated at 5000 kv-a. If these feeders average three miles in length there would be a total of 240 miles of feeder cable installed. If on this system there are five breakdowns per 100 miles per year, then there might be expected a total of 12 breakdowns per year on the system, or an average of one breakdown per month.

If the station capacity and the number of feeders are increased 50 per cent and the average length of feeder increased 331/3 per cent, then the breakdowns will average two per month. If all of the feeder cables are tied directly to the power station busbars and no reactors are used in either feeders or busbars, heavy short circuits occurring within a mile or so of the power stations would be felt over the entire system, and might be felt with troublesome severity even when occurring at greater distances from the power station. At times of light load, few machines are running and the portion of the short-circuit kilovolt-amperes carried by each machine on the system might easily be several times the normal load rating of each machine. Evidently one or two such general disturbances per month could not be tolerated. Properly designed feeder reactors limit the amount of short-circuit current in a feeder to such an extent that the effect is local.

CURVES

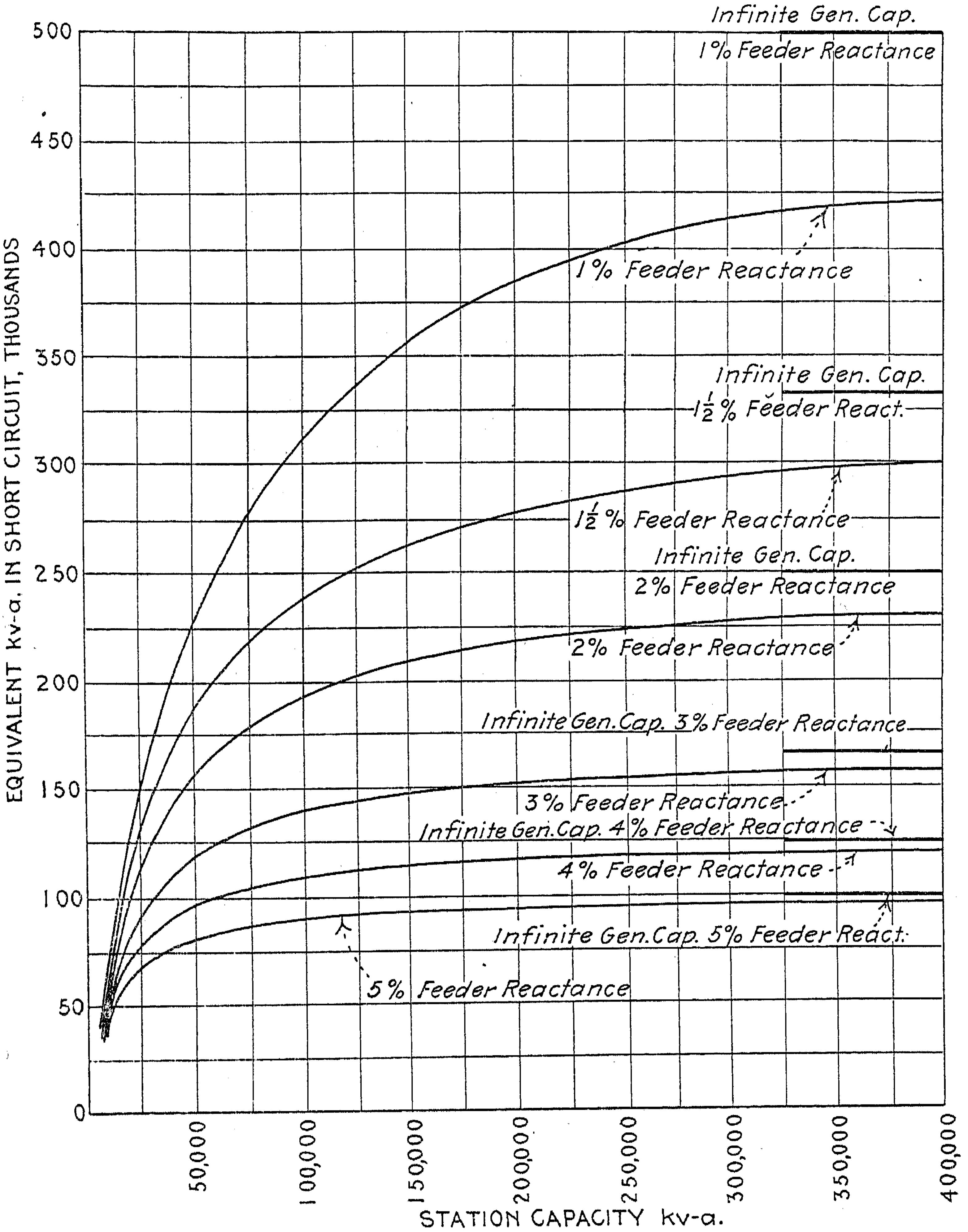
In order to study the effects of different values of feeder reactance several curves have been plotted.

Curve Sheet 1 shows the relation between the equivalent kilovolt-amperes in a short circuit and the station capacity in kilovolt-amperes for six different values of feeder reactance when no bus reactance is used. The generators in this case have 12 per cent inherent reactance.

Curve Sheets 2 and 3 show similar sets of curves which differ from the curves on Curve Sheet 1 only in the values of inherent generator reactance, which are chosen at 10 per cent and 8 per cent respectively.

The points of special interest shown by these curves are:

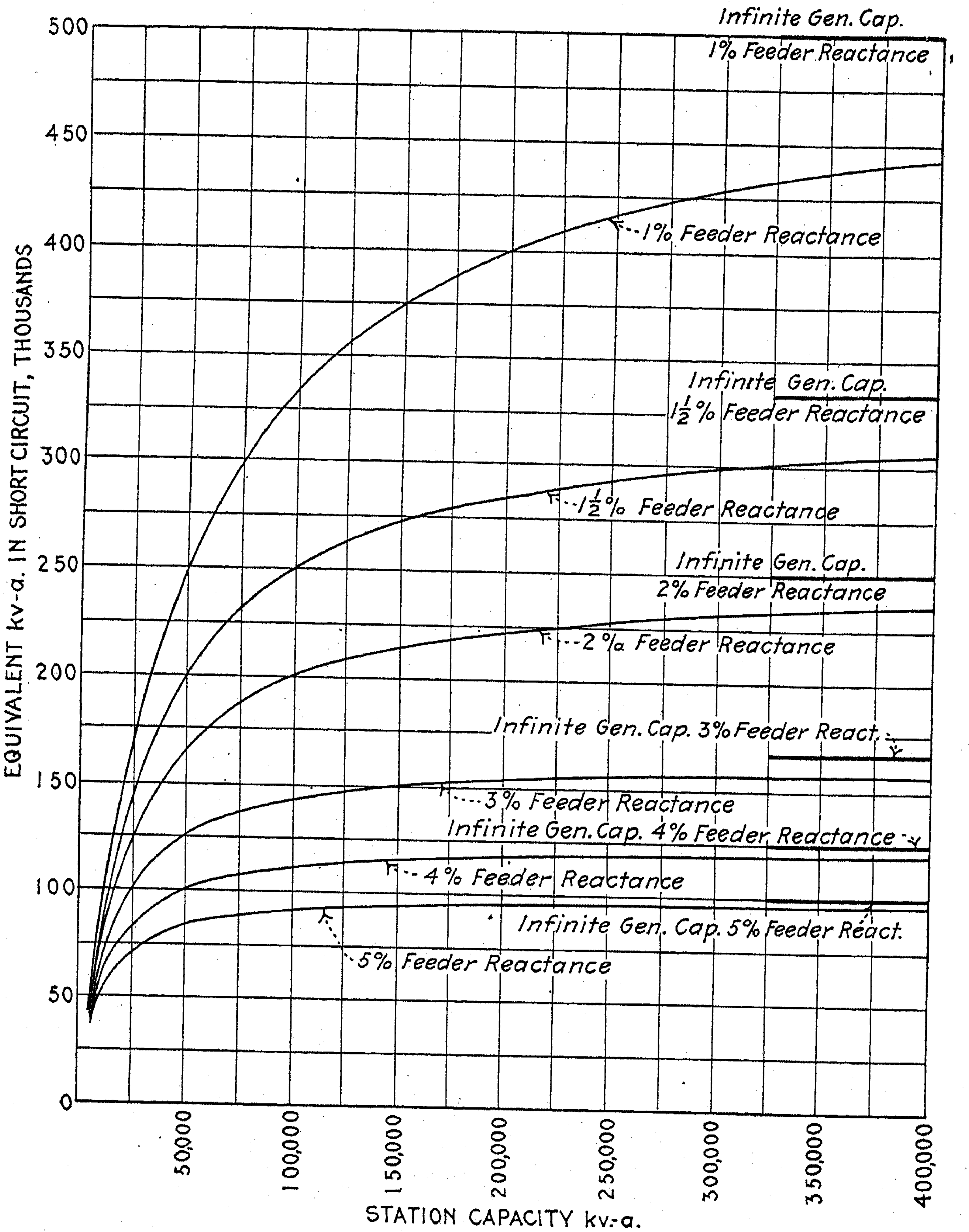
(a) With infinite generator capacity the equivalent kilovolt-amperes in a short circuit vary inversely as the reactance in the feeder circuit.



Curve Sheet No. 1—Curves Showing Values of Short Circuits in Terms of Kv-a. with Feeder Reactors of Various Per Cents—Inherent Generator Reactance 12 Per Cent without Bus Reactors—5000-Kv-a. Feeders.

(b) The equivalent kilovolt-amperes in a short circuit with infinite generator capacity are the same for the three sheets of curves.

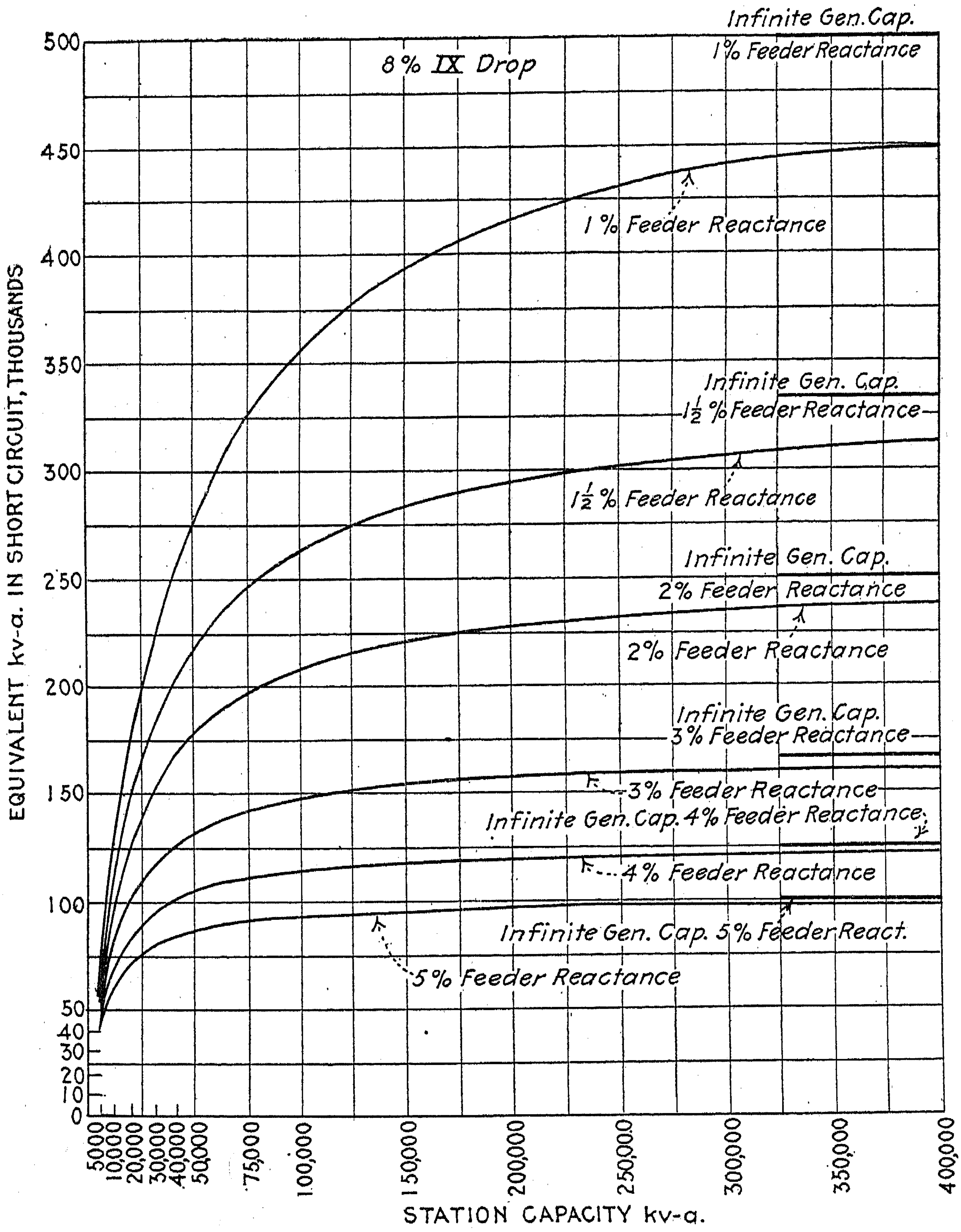
(c) The kilovolt-amperes in short circuit increase more rapidly per kilovolt-ampere of station capacity for a small station than for a large one.



Curve Sheet No. 2—Curves Showing Values of Short Circuits in Terms of Kv-a. with Feeder Reactors of Various Per Cents—Inherent Generator Reactance 10 Per Cent without Bus Reactors—5000-Kv-a. Feeders.

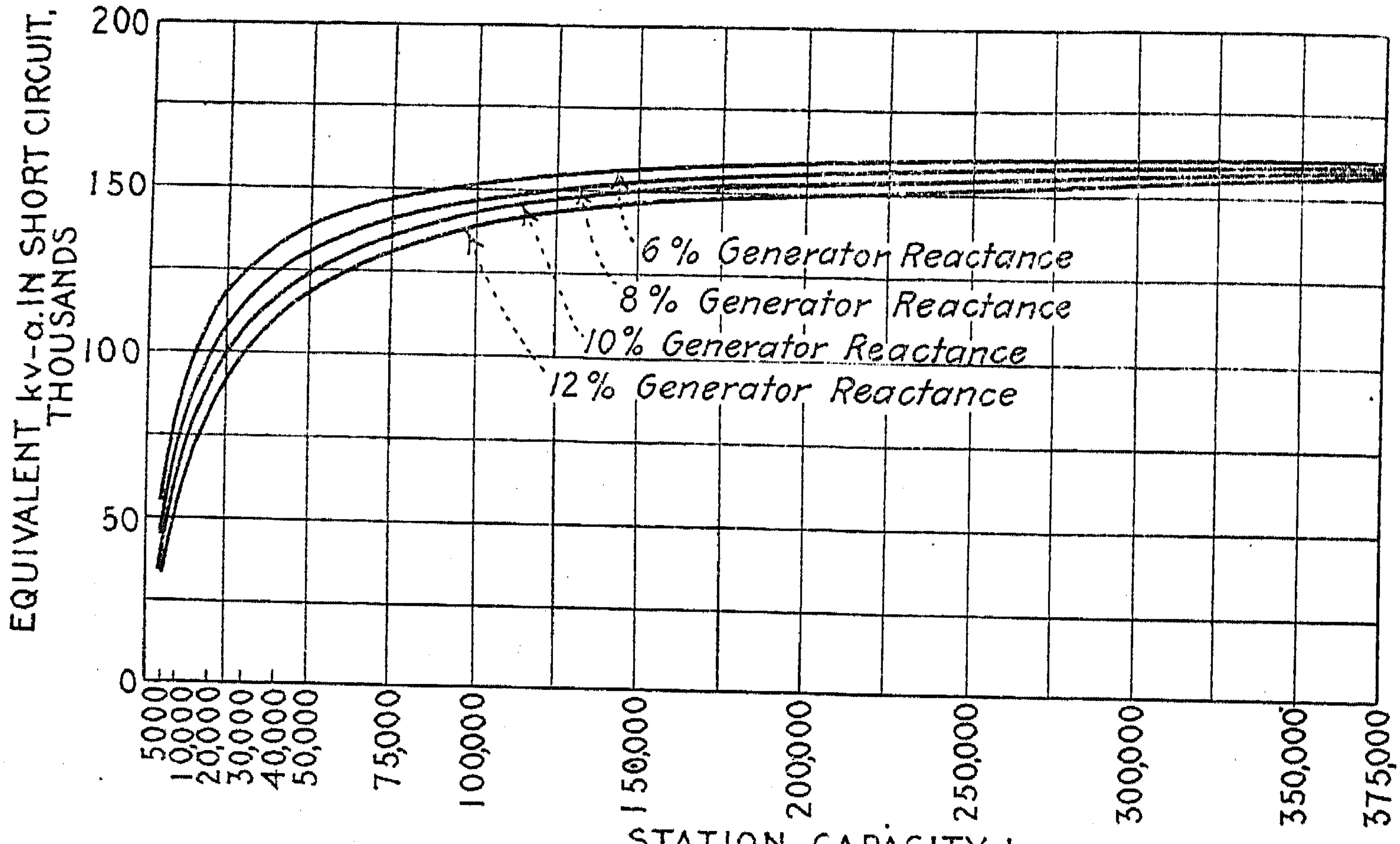
A comparison of similar curves on the three sheets shows that the variation in generator reactance does not greatly affect the curves. Curve Sheet 4 shows the four curves for 3 per cent (of

5000 kv-a.) feeder reactance replotted on the same sheet for generator reactance of 12 per cent, 10 per cent, 8 per cent and 6 per cent, respectively. By comparing the curve for 6 per cent generator reactance with that for 12 per cent generator reactance the small effect of the generator reactance on the curves is evident.



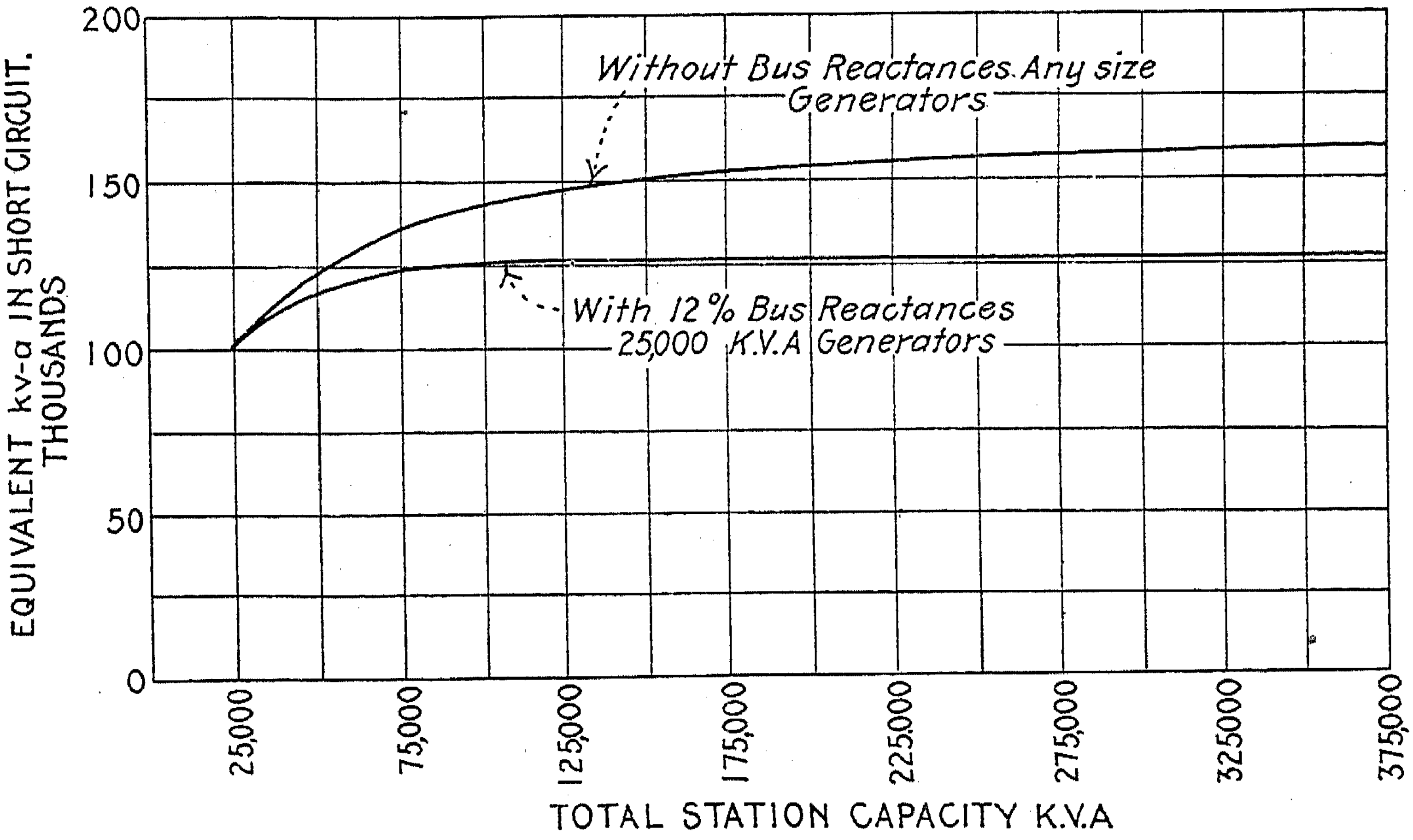
Curve Sheet No. 3—Curves Showing Values of Short Circuits in Terms of Kv-a. with Feeder Reactors of Various Per Cents—Inherent Generator Reactance 8 Per Cent without Bus Reactors; 5000-Kv-a. Feeders.

Curve Sheet 5 shows the relation between equivalent kilovolt-amperes in a short circuit and station capacity in kilovolt-amperes with 10 per cent generator reactance and 3 per cent (of 5000 kv-a.) feeder reactors, under two conditions. Under one condition no bus reactors are used. Under the other condition 12 per cent (of 25,000 kv-a.) bus reactors are used. The points of interest here are, that where 12 per cent bus reactors and 3 per cent feeder reactors are used, the equivalent kilovolt-amperes in a feeder short circuit becomes practically constant at 125,000 kilovolt-amperes station capacity, and any further increase in station capacity has no appreciable effect in increasing the short-circuit kilovolt-amperes. Where no busbar reactors, but 3 per cent feeder reactors are used, the short-circuit kilovolt-amperes increase until with infinite generating capacity they become 167,000 kilovolt-amperes.



Curve Sheet No. 4—Curves Showing Values of Short Circuits in Terms of Kv-a. with 3 Per Cent Feeder Reactors and Various Generator Reactances without Bus Reactors—Three-Phase Short Circuits—5000-Kv-a. Feeders.

Interpreted in another way, when the busbar reactors are used, the feeder reactors absorb 75 per cent of the voltage and therefore give a 25 per cent drop in voltage on the section of the busbars to which the feeder is connected, under the worst conditions of short circuit. This means that all of the feeders connected to that section will suffer a momentary drop in voltage of 25 per cent. Where no busbar reactors are used, the feeder reactor on the defective feeder will, under the worst conditions, absorb 100 per cent of the voltage and will pass 40,000 more kilovolt-amperes, but the voltage of the other feeders on the system will not be appreciably affected. If there were no possibility of a short circuit on the busbars or between the busbars and the feeder reactors and no possibility of a failure of the generator windings or connections between windings and busbars, it is evident that the use of feeder reactors alone is preferable to the combination of feeder reactors and busbar reactors, but with these live possibilities of trouble always present, busbar reactors should be considered. Whether or not they should be adopted depends upon the particular conditions of the system under consideration. It is evident that a very large power station without either bus reactors or feeder reactors is liable to short circuits which will endanger apparatus and service, due to the practically unlimited concentration of power in the short circuits.



Curve Sheet No. 5—Curves Showing Values of Short Circuits in Terms of Kv-a. with 3 Per Cent Feeder Reactors, 10 Per Cent Generator Reactance—With and Without 12 Per Cent Bus Reactors—5000-Kv-a. Feeders.

Bus reactance rating based on 25,000 kv-a. Bus reactors located between adjacent generating capacities of 25,000 kv-a.

Effect of Feeder Reactors on Voltage Regulation

At 0.8 power factor a 3 per cent feeder reactor will cause a voltage drop of approximately 1.8 per cent, at 0.9 power factor, a drop of approximately 1.3 per cent, at 0.95 power factor a drop of approximately 1.0 per cent, and at 0.98 power factor a drop of approximately 0.6 per cent.

In large city power stations such as have been considered, there is always a considerable amount of synchronous apparatus in operation at a high power factor and the voltage drop due to 3 per cent reactance in their feeders will be low.

THE PARALLEL OPERATION OF FEEDERS

The paralleling of a-c. feeders on a set of busbars at the substation end and the tying together of the different substation buses by means of tie feeders between substations would be highly desirable on most of our large city systems, if it could be safely accomplished. Such a method of operation would allow maximum facility in the interchange of power between various parts of the system, with a minimum amount of cable; the cables between the power station and each substation would be more evenly loaded and the total number of cables could be reduced. Because of the cables between substations, the necessity of idle reserve cables between power station and substations would be eliminated. During the period of peak load on a given substation, power would flow in over the tie cables from substations not carrying their maximum loads; and later when the conditions of peak were reversed the flow of power would be reversed.

THE EFFECT OF REACTANCE COILS ON THE PARALLEL OPERATION OF FEEDERS

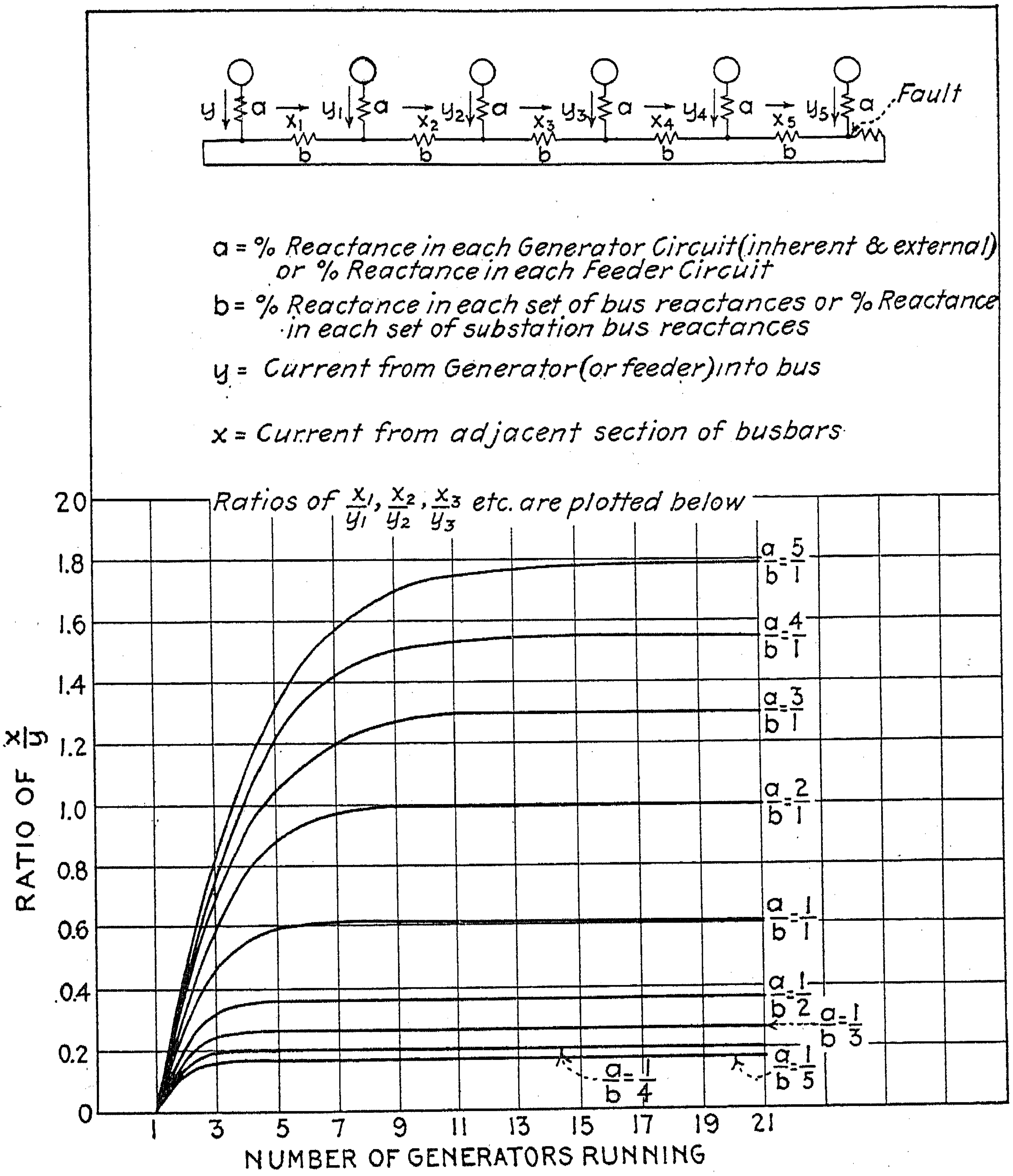
To assist in the study of the amount of short-circuit current which can flow into a fault, the series of curves on Curve Sheet 6 was plotted. These curves can be applied to approximate the amount of short-circuit current into a fault on the busbars of a power station where busbar reactors are used, or to approximate the amount of short-circuit current into a fault on or near the substation busbars where several feeder cables are connected in parallel on the substation busbars with busbar reactors between them.

As applied to the case of a power station, one or two examples will be cited. Assume the case where the ratio of generator reactance to busbar reactance (a/b) equals 1/3. The corresponding curve is almost constant with three running generators. This means a short circuit on any section of the busbars is practically maximum when the generator on the same section and one generator on each adjacent section are in operation, and the addition of more generators to the system will not appreciably increase the amount of short-circuit current.

Where the busbar reactance and generator reactance are equal ($a/b = 1/1$) the maximum value of current is nearly reached with five generators running.

In applying the curves to a substation, consider the following concrete example:

Consider a case in which the inherent reactance in each feeder equals 1 per cent, artificial reactance equals 3 per cent, and bus reactance equals 3 per cent, all based on 5000 kilovolt-amperes. Then if a short circuit occurs on or near the substation busbars the kilovolt-amperes flowing in over the short-circuited line equal $\frac{5000}{0.04}$, or 125,000 kv-a. $a/b = 4/3 = 1.33$. From curves, by



CURVE SHEET No. 6

interpolation, $x/y = 0.75$. Hence, the kilovolt-amperes flowing over each adjacent bus reactor equal $0.75 \times 125{,}000 = 93{,}750$ kv-a. and the total kilovolt-amperes flowing into the fault $= 125{,}000$ kv-a. $+ 2 \times 93{,}750$ kv-a. $= 312{,}500$ kv-a.

The 93,750 kv-a. flowing in over each bus reactor are composed of two components, one flowing in over the second reactor and the other over the adjacent line. These also bear the relation to each other of x/y ($= 0.75$). Hence, over the second reactor there flow in 40,180 kv-a. and over the adjacent feeder 53,570 kv-a.

In this case with 125,000 kv-a. flowing into the fault from the feeder on the same section with the fault, and 53,570 kv-a. over each adjacent feeder, it is probable that all three of these feeders will go out at once and these will be followed by the other feeders in the substation.

Consider another case in which the total reactance in the feeder is as high as 10 per cent, and the bus reactance is also 10 per cent. (Both based on 5000 kv-a.). Then, in case of a short circuit on or near the substation busbars, the kilovolt-amperes flowing in over the line equal $\frac{5000}{0.10}$ or 50,000 kv-a. $a/b = 1$. From the curve, $x/y = 0.62$. Hence, kilovolt-amperes flowing over each adjacent bus reactor $= 0.62 \times 50{,}000 = 31{,}000$, and the total kilovolt-amperes flowing into the fault $= 50{,}000 + 2 \times 31{,}000 = 112{,}000$ kv-a.

The 31,000 kv-a. flowing in over each bus reactor are composed of x and y components bearing the relation $x/y = 0.62$. Hence, over the second reactance there flow in 11,850 kv-a. and over the adjacent feeder, 19,150 kv-a.

In this second case 50,000 kv-a. flow in over the feeder connected to the faulty section of the busbars, while 19,150 kv-a. flow in over the adjacent feeders. It is therefore probable that with the ordinary relay setting, all three of these feeders will go out at nearly the same time and that these will be followed by others. Furthermore, such large reactors in feeders and substation busbars would have a serious effect on the voltage regulation of the system, and would in a large measure defeat the purpose of their installation, viz., to permit the free interchange of power between different parts of the system.

Another arrangement of feeder reactors would be to place reactors at both ends of the feeders and omit the reactors from the substation busbars. This scheme would be more objectionable than the one discussed above, because a short circuit on the substation busbars would be fed by the several feeders in parallel, and, if these feeder circuits were all alike, the kilovolt-amperes flowing into such a short circuit would be directly proportional to the number of feeders connected to the substation busbars.

Several power stations of about 50,000-kv-a. generating capacity are operating today with feeders tied together at the substation end. In several of these stations it has been noticed that a severe feeder short circuit usually trips out several feeder switches and sometimes causes a general interruption to service.

The above analyses show that even on feeders from a very large generating station, feeder reactors of moderate size effectively limit the amount of current flowing from the power station end into a short circuit on the feeder. On the other hand, if this feeder is one of a number of feeders connected in parallel at the substation end, a short circuit will have a back feed from all of the other feeders connected to the substation busbars. The amount of kilovolt-amperes flowing over these other parallel feeders is likely to be sufficient to trip out part or all of the oil switches on these circuits.

SUMMARY

In a large city power system, the miles of underground cable and consequently the cable faults increase at a faster rate than the generating capacity. The severity of short circuits also increases with increased generating capacity. Feeder reactors are particularly effective in reducing and localizing the effect of such short circuits. When properly proportioned feeder reactors are used, an increase or decrease of generator reactance has only a limited effect on the amount of kilovolt-amperes flowing into a fault. Bus section reactors in the generating station in connection with feeder reactors still further reduce and localize these effects, even when it might be more desirable to distribute their effect if other conditions permitted.

It would be desirable for many reasons to operate feeders in parallel at their substation ends, but such operation tends to increase greatly the kilovolt-amperes flowing into a feeder short circuit and to cause other feeders besides the one affected to trip out when overload relays with the usual settings are used.

Presented at the 299th meeting of the American Institute of Electrical Engineers, New York, October 9, 1914.

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USE OF REACTANCE WITH SYNCHRONOUS CONVERTERS

AN INSURANCE OF CONTINUITY OF SERVICE AND A PROTECTION OF APPARATUS

BY J. L. MCK. YARDLEY

ABSTRACT OF PAPER

The paper presents the results of overload and short-circuit tests made about two years ago upon some synchronous converters in circuit with auxiliary reactors.

Two entirely separate sets of tests upon two synchronous converters of widely different operating characteristics are described. In the one case the reactor is in the a-c. circuit and in the other in the d-c. circuit; yet in each it may be called, and in fact is, a protective reactor.

In presenting this original information the author, with a view to indicating its commercial application and hoping to provoke discussion, has endeavored to divide synchronous converter installations in a general way into classes with respect to the need or desirability of employing protective reactance, and also with respect to the general design or type of the reactor to be employed. In order to do this, synchronous converter installations are divided into a few general classes with respect to the character and exactions of the service conditions under which they are required to operate.

The paper was written shortly after the tests were made, but although much has been learned or written about protective reactors since that date, the author believes nothing has transpired to affect the value of these tests or to make it necessary to change the form in which it was originally intended to present them.

SYNCHRONOUS converter installations considered with regard to the relative importance of service and apparatus may be divided into three classes:

I. Installations where it is of prime importance to keep voltage on the lines at all times.

II. Installations where heavy overload sare frequent but where, to protect apparatus and accordingly maintain service, the voltage may be allowed to drop off during the overload.

III. Installations where high momentary overloads are frequent, unattended by appreciable voltage drop, but where brief even though comparatively frequent interruptions to service are not objectionable in order to protect apparatus.

I. Installations of the first class are found feeding the network of circuits forming the distribution system of a metropolitan lighting and power company. Here the aggregate of power handled is the largest found in any power systems. The generating, transforming and converting stations are of the largest and most highly concentrated. The customers are the most numerous and the most widely distributed. The service required is the most varied in quality and quantity.

In such a system, handling an enormous aggregate of power, there is a large demand for service every hour of the twenty-four, every day in the year. Any failure, of however brief duration, to supply this demand means a great aggregate loss to the customer in money and convenience. In such a system, where immense quantities of power are generated in a concentrated generating station or group of stations, passed out through diverging feeders, transformed and converted in a plurality of substations and finally delivered 24 hours per day through a multiplicity of circuits to the ultimate consumer, the secret of satisfactory service lies in the smooth and orderly working of the various parts of the system. The difficulties in the way of securing uniform operation of such a quantity and variety of apparatus have been overcome only through great engineering skill. The method of operation is carefully prearranged and the various pieces of apparatus are started and stopped according to a schedule so as to make the service continuous. It is a tremendous undertaking to start and place in normal operating condition all the apparatus on the system when once it has been shut down. The utmost perfection of cooperation between men is required. A very severe strain is placed upon the power company's apparatus, while the delay and loss to the consumer incident to interruption is absolutely prohibitive. It becomes, therefore, a matter of necessity to maintain voltage on the customers' circuits at all times.

The direct-current feeders are interconnected at many points. A short circuit or ground on one feeder would trip out the overload breakers at a number of stations and thereby completely remove voltage from a comparatively large section of network. It is, therefore, considered preferable to omit automatic tripping features in the d-c. feeders. A short circuit or ground must, therefore, burn itself free or be eliminated only by some of the a-c. circuit breakers or apparatus letting go. In some of the very largest systems, the current-carrying capacity of the largest feeder is so small compared to the momentary overload capacity of the feeders to which it is tied, and of the apparatus supplying them, that the trouble almost immediately clears itself. The total voltage is available at the scene of trouble. An arc of such magnitude is formed in consuming this voltage that the trouble shortly burns through. The voltage being consumed in the feeder having the fault, the remaining feeders continue supplied with scarcely reduced voltage and the apparatus running from them is scarcely affected. In these systems the trouble clears itself without seriously overloading the substation apparatus. In case the trouble should exist in the immediate vicinity of a substation so that substation would tend to carry the entire trouble, that substation would be saved from damage by the tripping out at the generating station of the a-c. supply feeders. The trouble would then, if it lasted long enough, be thrown on the remaining substations, which would more or less equalize it, and on account of their great capacity would be able to carry it until it cleared itself. There is, accordingly, no need of protective reactance in a substation of this character.

In systems of this general character but of somewhat smaller dimensions the current capacity of the largest feeder bears a less desirable ratio to the overload capacity of the feeders and apparatus supplying it. There are three immediate results:

(a) The trouble does not clear so quickly, as the current at the reduced voltage available at the trouble is not so great.

(b) The voltage on the other feeders falls off appreciably from the normal condition. Lights dim and motors slow down, but, in general, all apparatus continues to operate and a general shutdown does not result. The apparatus on the particular feeder in trouble probably stops owing to the greatly reduced voltage.

(c) Greater momentary overloads are thrown on all the supply apparatus. It is important, therefore, to give the apparatus characteristics such as to enable it to withstand these overloads satisfactorily.

The converting apparatus is usually a synchronous converter, though in some installations motor-generator sets are employed. These motor-generator sets have not the momentary overload kilowatt capacity of the converter. Usually the motor will pull out of step before the generator is dangerously overloaded. The synchronous converter will, in general, carry several times more kilowatt load than the motor-generator set before dropping out of step. It will carry so much overload before failing in this respect that the effect upon commutation must be considered. In the case of a shunt-wound motor-generator set, owing to the poor voltage regulation of the generator, the current which can be commutated before the motor pulls out approaches more nearly the value of current which can be commutated by the converter. Some tests which will be given later on show that it is possible to throw six times normal full load current on some converters before they will flash over. It is obvious, however, that the actual possible limit of the converter is not the limit which must be observed in a commercial case. Assuming, therefore, that the converter will carry 400 per cent normal load current for a time comparable to that required for d-c. line trouble to burn itself free, it remains to equip the converter with auxiliaries which will enable it to escape all load in excess of this amount. There are several ways in which this may be accomplished when it is first known how much the voltage must be reduced.

1. In the case of a booster or split-pole converter the voltage can be lowered to the full buck value at any desired overload by means of relays in the d-c. circuit actuating the voltage-controlling element of the converter. On account of the time element of the relays and rheostat and the magnetic lag in the iron circuit of the converter this method is probably not quick enough.

2. A resistance short-circuited by a circuit breaker may be placed in the d-c. lead. The breaker would be tripped at some fixed value of current and the resistance placed directly in circuit. Owing to the time element of the ordinary overload circuit breaker this method is probably not quick enough.

3. With reactance placed in the a-c. circuit, a series field can be added to the main poles acting in opposition to the shunt winding, so that the power factor becomes badly lagging on overloads and the reactance produces a drop in voltage. This involves a series field on the converter, and the overload capacity of the converter is further limited by the wattless armature currents caused by the overload current in the series field.

4. A larger amount of permanent reactance may be placed in the a-c. circuit so that, even with a shunt-wound converter and approximately constant power factor, a great drop in voltage will occur at large overloads.

The fundamental objection which has been raised to apply to this last method as well as to the other methods suggested is that, owing to the inertia of the rotating part, the synchronous converter, in common with the direct-current generator, delivers an instantaneous direct current when the resistance of the external d-c. circuit is suddenly reduced, which can not be reduced by any of the means suggested and which, particularly in the case of the converter, is likely seriously to affect the commutation.

Without debating this question, it is proposed to state that with a reactor of the air-core or unsaturated type in the a-c. circuit, there is no question but that the voltage drop across the reactor will follow instantaneously and exactly the alternating-current variations. It follows that, if the alternating current is at all times approximately proportioned to the direct current, a reactor may be employed in the a-c. circuit to limit the overload current which the converter can deliver.

Assuming a reactor of 30 per cent, the voltage impressed at the collector rings under several conditions of load is shown by the side *A* in the triangles of Fig. 1. The effect of the varying reactive drop *B* is to vary the phase angle of the voltage impressed at the collector rings. The converter must therefore be well equipped with dampers so as to follow closely these phase variations. The line voltage is the constant vertical line *C*.

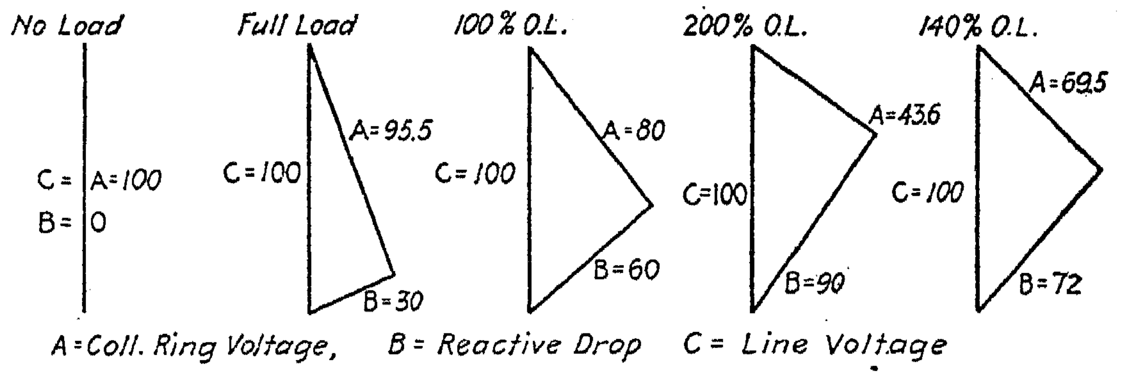

FIG. 1—SYNCHRONOUS CONVERTER—EFFECT OF 3 PER CENT REACTANCE IN THE A-C. SUPPLY CIRCUIT

With these factors in mind, it is proposed to describe some tests which were made to determine the suitability of reactors for such service in connection with a converter under a certain set of known conditions.

A certain 250-volt three-wire Edison system enjoying the enviable record of having maintained voltage on the bus over a long period of years was the subject of this study. Ordinary feeder troubles have drawn the substation bus voltage down to 180 volts or 200 volts. In one or two cases of very severe trouble the bus voltage has been drawn down to approximately 160 volts, that is, to 64 per cent of normal, before the trouble cleared itself without a general shut-down. The amount of reactance required, therefore, for a converter on this system is such as will draw down converter voltage to 64 per cent of normal before the overload exceeds the limits of the converter.

A 250-volt converter was not available, but a 280-volt, 1000-kw., two-phase, 60-cycle, 600-rev. per min. commutating-pole booster converter with voltage range of from 240 to 320 d-c. was available. This converter was wired up to a bank of three-phase-two-phase transformers, in the circuit to which were placed three air-core reactors. The converter was loaded on rack resistors. The load was thrown on by closing a knife switch and was tripped off by means of a d-c. circuit breaker. One element of the oscillograph was arranged to show the voltage of the a-c. supply circuit outside of the reactance coils, for the purpose of showing that to a large degree the reduction of the d-c. voltage came about independently of any reduction in the voltage of the supply circuit. The other two elements of the oscillograph were arranged to show the direct current and voltage, which are the quantities of particular interest in determining the effect of the reactance. There was approximately 30 per cent reactance in the circuit in coils and transformer. There was a drop of not more than 5 per cent in the line voltage; but, due to the reactance and a large resistance drop in the converter, transformers and leads, the converter direct voltage at 8600 amperes output—that is, at 2.4 normal load—was reduced 50 per cent, to 140 volts. See Figs. 2, 3 and 5. Figs. 4. and 6 show the record of a second oscillograph. Fig. 4 was taken simultaneously with Fig. 3, and Fig. 6 with Fig. 5. They show the low-tension voltage at the collector rings and the voltage across the reactance coil in the high-tension circuit. Fig. 5 was taken to see if the hunting would dampen out, and the load was held a total of 8 4/5 seconds, which is much longer than the average line trouble takes to clear itself.

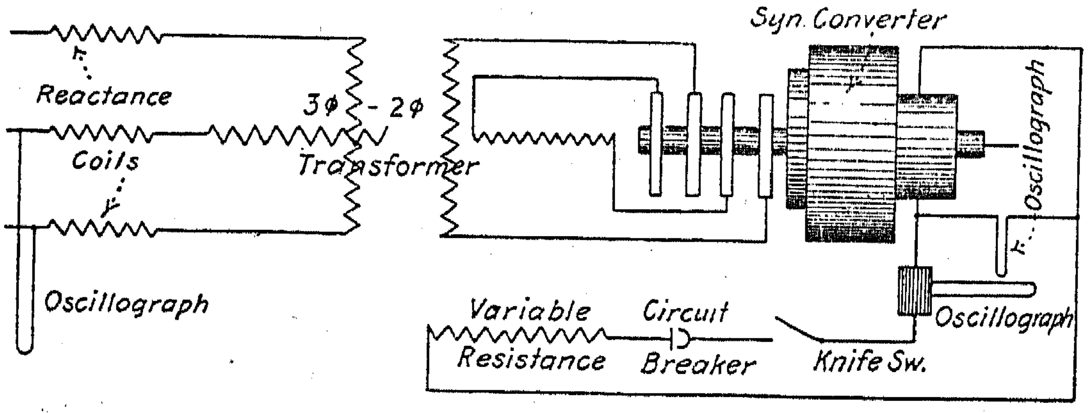

FIG. 8—CONNECTIONS FOR CURRENT-LIMITING REACTANCE

The synchronous converter employed was provided with relatively inefficient dampers, and there was marked hunting at approximately 80 alternations per minute when load was first thrown on, owing to the shift in phase angle of the voltage im-

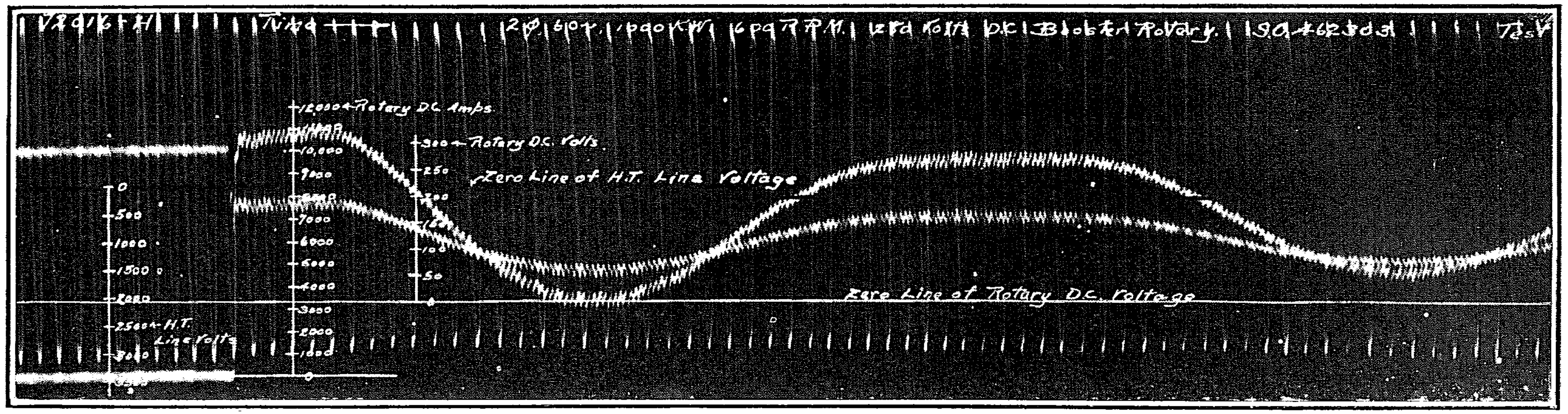

FIG. 2

[YARDLEY]

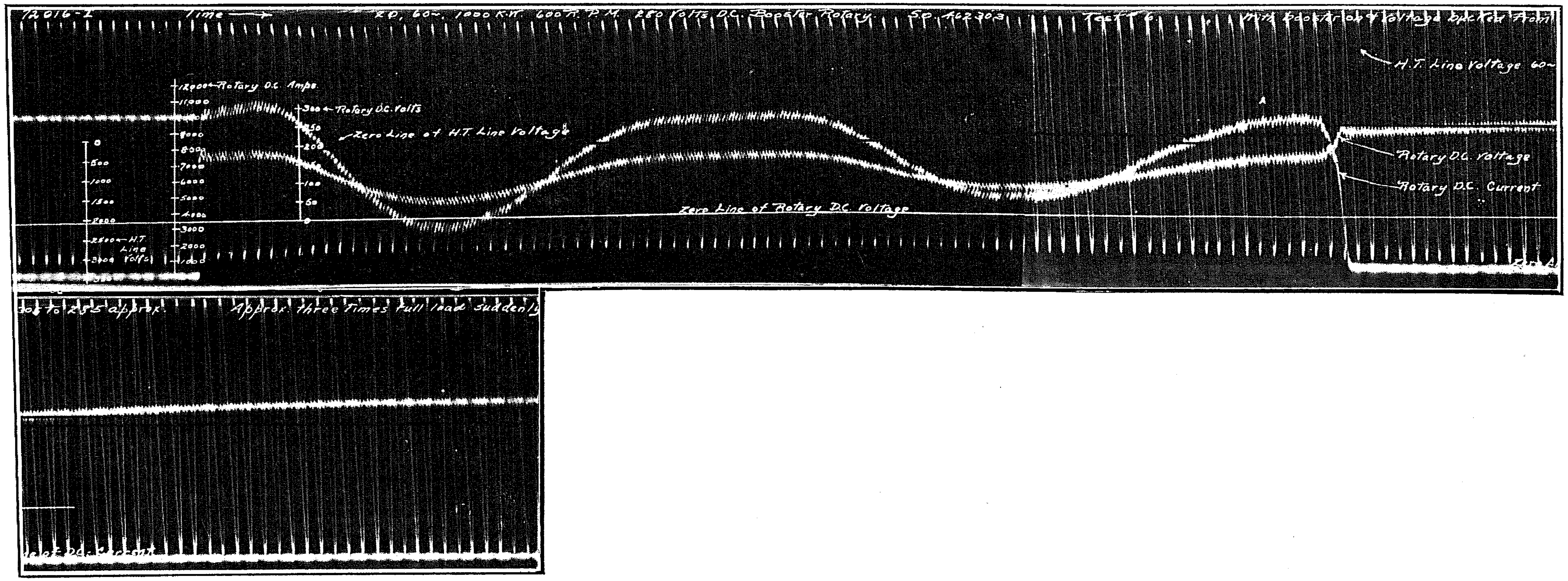

FIG. 3

[YARDLEY]

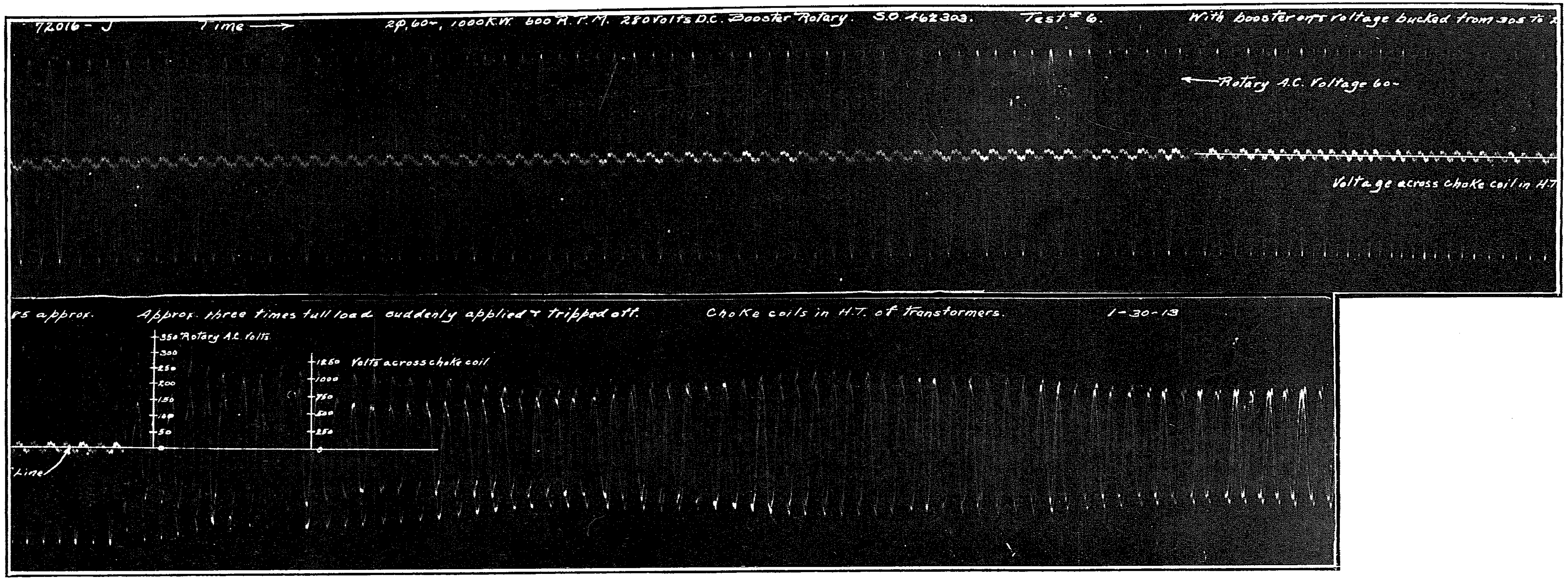

FIG. 4

[YARDLEY]

PLATE CXVIII.
A. I. E. E.
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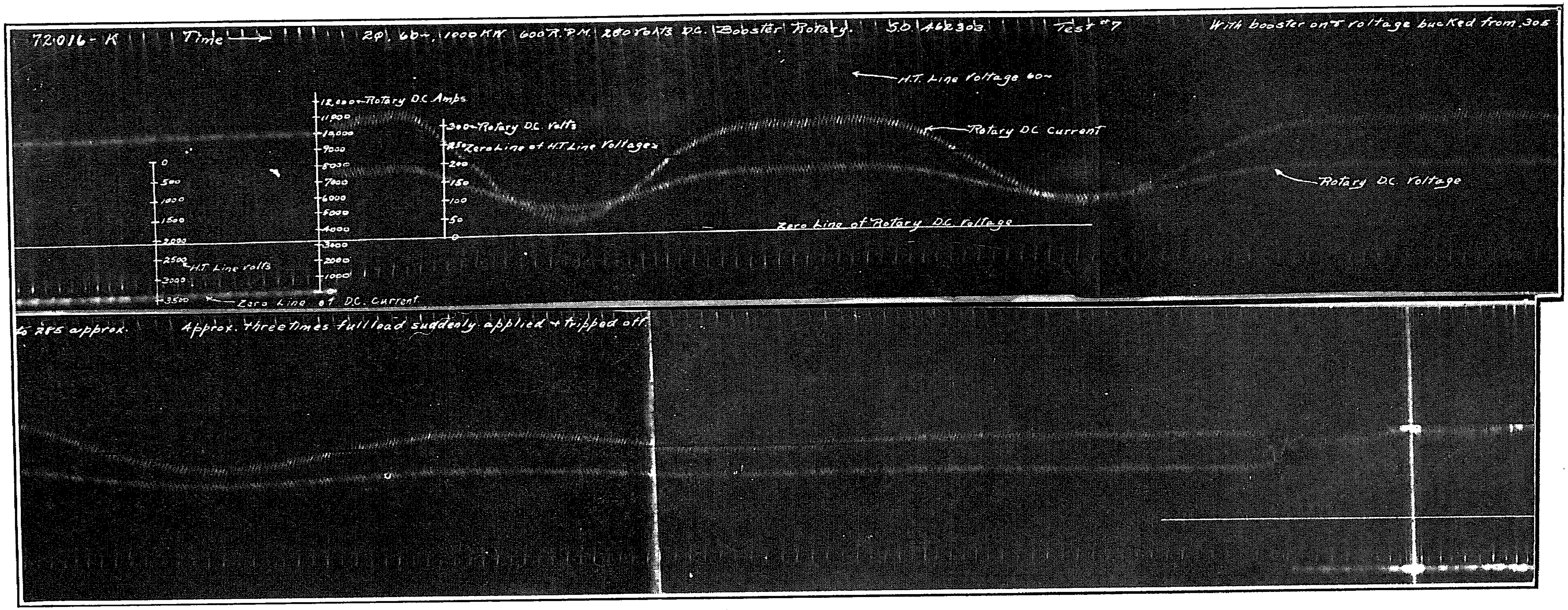

FIG. 5

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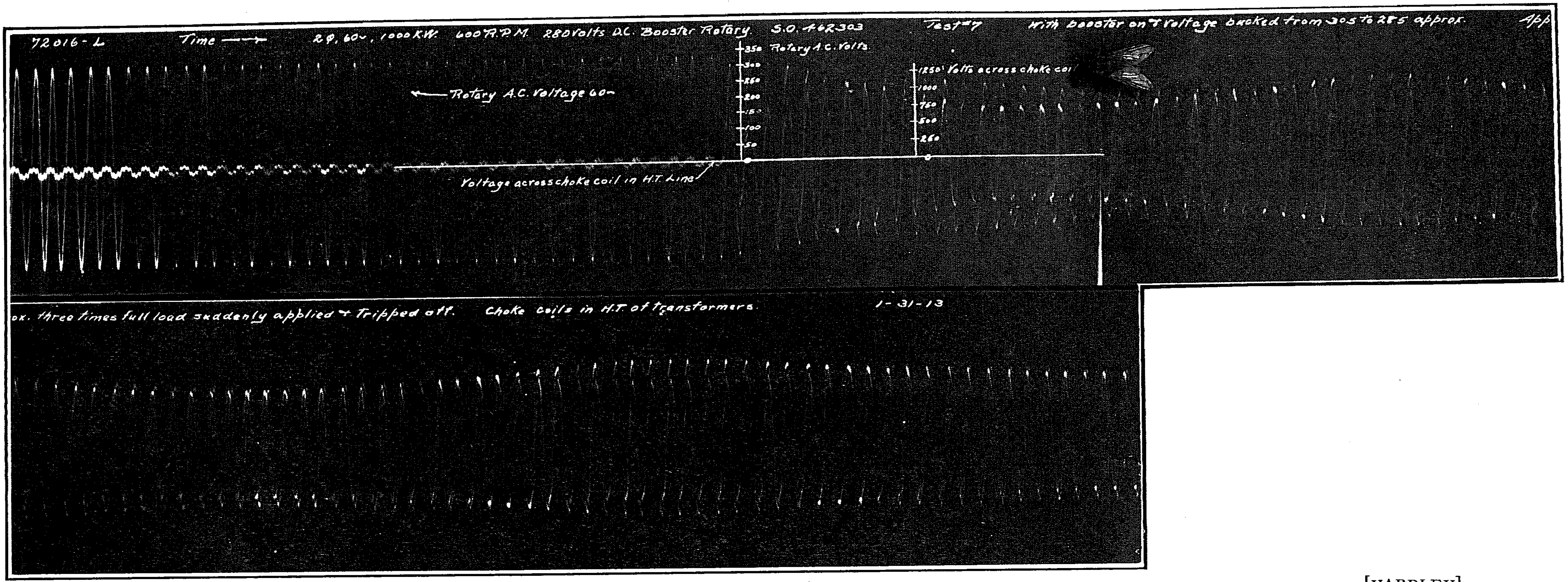


FIG. 6

[YARDLEY]

pressed at the collector rings. There was severe sparking at intervals corresponding to the period of hunting, which practically died out as the hunting ceased. The sparking was not so severe but that the load might very probably have been further increased or the reactance reduced, without exceeding the flashing limitations of the converter even with its ineffective dampers. This hunting and sparking would have been greatly reduced and possibly entirely eliminated if the converter had been provided with a damping winding of better design. There was no appreciable instantaneous d-c. generator effect, as the circuit was closed, which could be separated from the hunting action, and the tests were considered by a large number of engineers who witnessed them to show very conclusively the value of reactance used in such an application.

II. The substations on large or medium size interurban railway systems are in the class of installations which are subject to heavy overloads, where it is, in general, satisfactory that the voltage on the lines shall drop off and vary considerably during the overloads in order that the supply apparatus may be protected from injury. The size of the individual piece of converting apparatus is small compared to the capacity of the transmission system of trolley wires and feeders, though it is still large compared to the maximum momentary overload likely to be thrown on it. This is owing to the number of converter substations which will be in parallel and will divide any abnormal overload. In the case of a short circuit or ground on a d-c. feeder, there is great likelihood that the trouble will burn itself free as in the first class of systems, the capacity of a single feeder or trolley wire being small, relative to the size of the whole system.

These systems are large enough to have carefully worked out train schedules and to require close adherence thereto. Uniformity of trolley voltage is therefore an important requisite and the supply apparatus is given a voltage characteristic which continues to rise for all moderate overloads. In many cases compound-wound converters with suitably chosen series field and reactance are employed.

With a shunt-wound converter considerable voltage variation would be experienced unless the a-c. and d-c. reactance and resistance drops should happen to be quite small. With considerable series field and unsaturated reactor, a converter would continue to take on load, owing to its approximate straight-line rising voltage characteristics, and some means must be supplied to prevent this load from reaching a value under abnormal conditions which would be injurious to the converter. There are disadvantages in having this protection in the form of a circuit breaker, since such a form of relief simply throws a greater overload upon the remaining converters on the system when one trips, and a general shut-down may result. It is much preferable to have the converters in each substation protected in such a manner that, in case a short circuit, grounded feeder, or abnormal load due to the bunching of cars occurs at any point of the system, the converters in the immediate vicinity will continue on the line, carrying all the overload they are able to carry. By providing a voltage characteristic which will droop before the critical safe overload is reached; the excess load is automatically distributed among the converters elsewhere on the system without actual interruption of service or drop in trolley voltage such as need affect the time schedule. The drooping characteristic on overload is obtained by employing a saturating iron-core reactor. Iron-core reactors have been installed in some of the largest substations in the country to equalize the load between transformer synchronous converter units having different inherent regulation characteristics. The use of them to divide the load between the different substations of a system, and by the voltage drop they produce thus to protect the individual substation apparatus from injury, thereby tending to secure continuity of service, is therefore but a wider application of the well-known functions of a well-known piece of apparatus.

III. The substations on small and medium size interurban railway systems are in the third class of installations. One converter supplies a comparatively long section of trolley line on which there is a comparatively small number of cars running at relatively long intervals. The drop in trolley line and feeder to points distant from a substation is considerable. Additional drop in reactance would be objectionable under normal operating conditions. The converter should have a rising voltage characteristic, therefore, to take care of the normal operating conditions. It must, however, have some protection from d-c. short circuits and abnormal overloads, particularly when these occur close to a substation. The overloads have a maximum so much greater than the average load and are, relatively, so infrequent that neither of the two previous methods of protection is best adapted. In this case it is necessary actually to get the converter off the line to prevent damage. The bigger the momentary overload which can be carried before tripping off, the better, but momentary interruptions are not serious (particularly as in such a system the feeders and trolley wires are usually sectionalized so that a trip-out at one substation does not mean an interruption on the whole system) and the converter *must* be protected, at a temporary expense to service if necessary.

There is a limit to the current which any commutating machine will commutate without flashing over. This limit of instantaneous commutating capacity is usually way above the permissible capacity for any appreciable time limited by armature heating. The breaker may then be set considerably above any guaranteed overload value on such a system as we are now discussing, where the overloads, though very great, are very brief. A converter will also usually carry a much greater load momentarily than it will permit to be tripped off without flashing. Now there are certain auxiliaries which will greatly increase the severity of the short circuit to which the converter may be subjected without feeling it. If it is possible to throw overloads of five to six times normal on a converter before it will flash, the auxiliaries must prevent any excess beyond that amount. These auxiliaries consist of a reactor to introduce a time element in the rise of current when the short circuit is established, and a quick-acting circuit breaker. These two must be proportioned so that the trouble will be cleared before the current has reached a value which the converter can not safely commutate nor stand being tripped off. The reactance must be of the air core or unsaturated type and the breaker must necessarily be quite different from the ordinary d-c. carbon circuit breaker, which has a very appreciable time element.

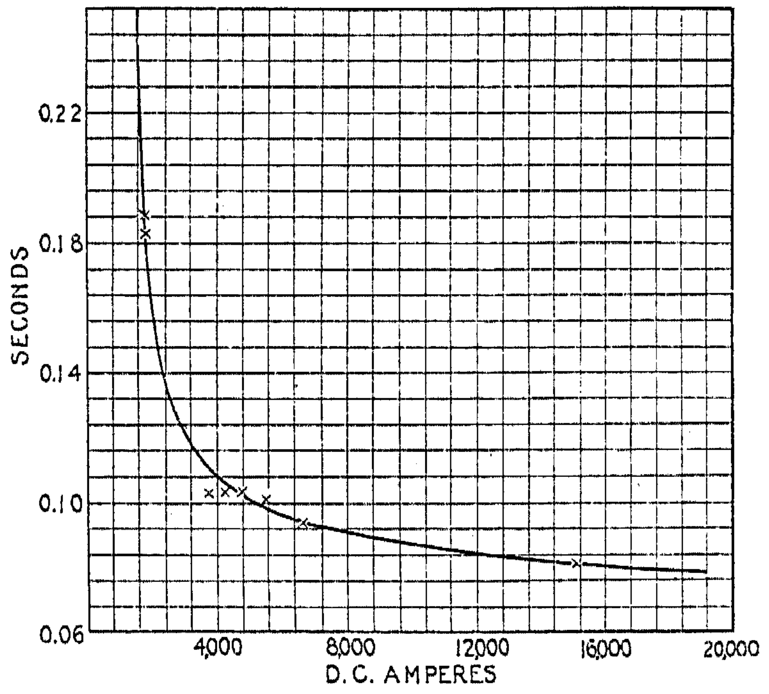
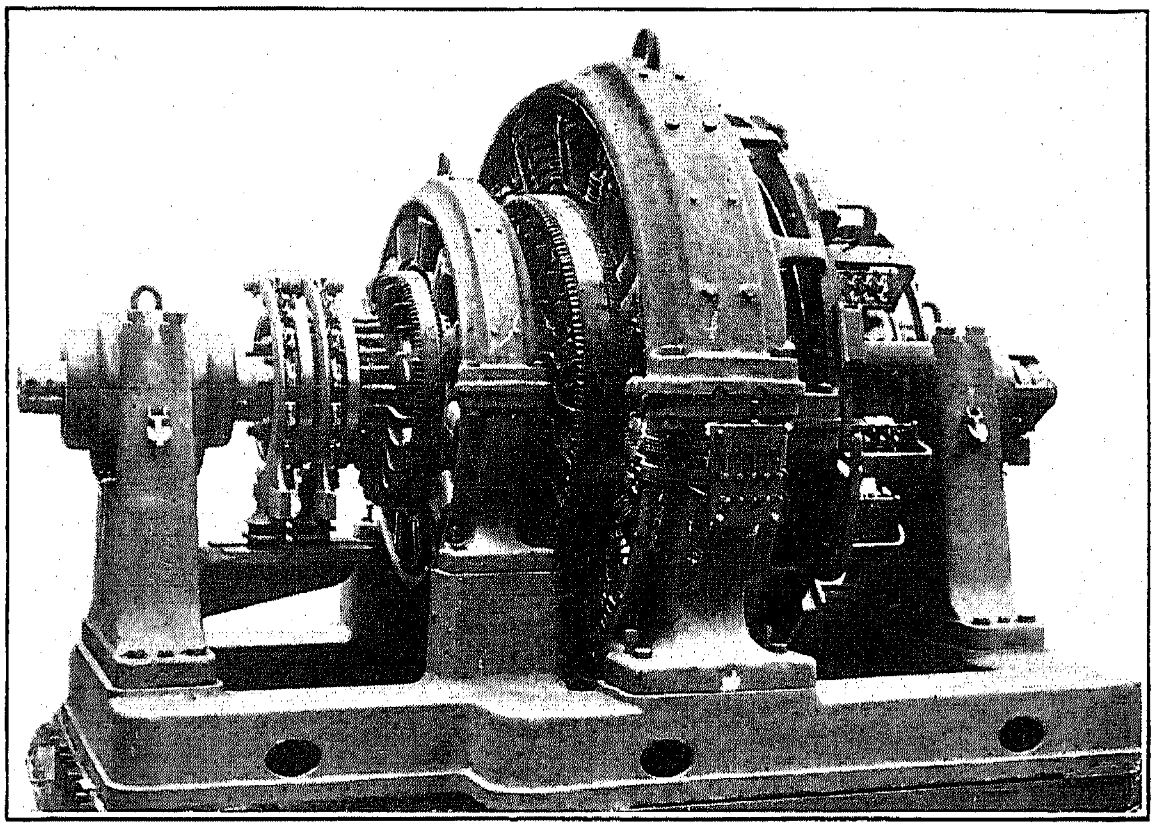


FIG. 9—TIME OF OPENING OF 1600-AMPERE, 600-VOLT CIRCUIT BREAKER

The ordinary carbon type d-c. circuit breaker has a time element which would require a prohibitive amount of reactance. Curve Fig. 9 gives the time element of an ordinary circuit breaker of 1600 amperes capacity. This gives the time for the mechanical operation only. Figs. 12-15 show the time taken by such a breaker to open the circuit.

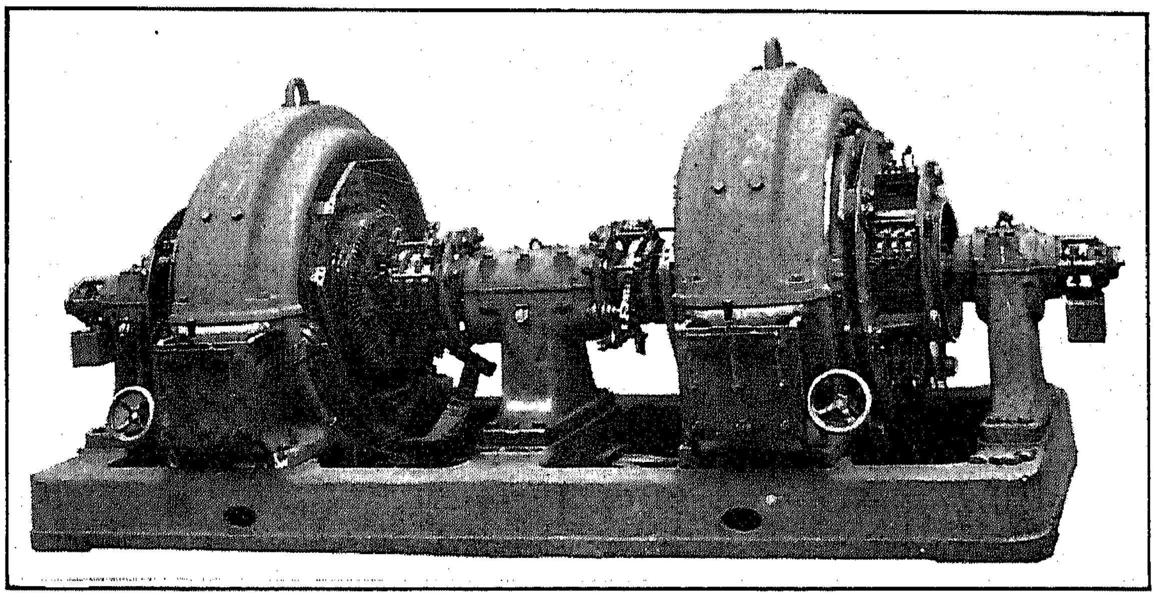
The high-speed circuit interrupter as developed by Messrs. Fortescue and Mahoney consists essentially of an ordinary single-pole breaker, the parts of which are accelerated by means of a heavy steel spring. After the spring has ceased accelerating, the momentum of the moving parts is gradually absorbed by means of a dash pot, so that the mechanism is not injured by sudden stopping. The breaker is provided with magnetic blow-outs and a special condenser-operated tripping device, the moving parts of which are designed to have a minimum of friction and moment of inertia.

The operation of the tripping device depends upon well known characteristics of a direct-current circuit, as follows: Under steady conditions of load the only resistance offered to the flow of current is the ohmic resistance of the conductor. If the circuit were absolutely non-inductive, current changes due to change of resistance would take place at an infinite rate, but due to the fact that inductance is always present in any circuit, the current takes an appreciable time to reach a definite value. This is due to the e.m.f. set-up by the inductance, which is proportional to the rate of change of the current, and is in opposition to the impressed e.m.f. of the circuit. Thus if I_0 be the current in a circuit whose resistance is R_0, if the resistance of the circuit be suddenly changed to R_1, the e.m.f. of self-induction must be equal at the instant of change to $I_0\ (R_0 - R_1)$. The back e.m.f. of self-induction is therefore in a measure proportional to the severity of the short circuit. If a condenser connected in series with an electromagnet be shunted across the circuit, when the sudden overload or short circuit takes place there will be a drop in the e. m. f. across the condenser due to the inductance of the lines between the source of e. m. f. and the point at which the condenser and magnet are connected, proportional to $I_0\ (R_0 - R_1)$, and the condenser will discharge through the magnet. By using a proper value of capacity the magnet may be made to operate at any required value of this back e. m. f., provided that R_1 be not greater than a certain value, which depends on the line constants of the circuit and the periodicity of the condenser and magnet. Should R_1 be greater than this value the trip will not operate, because it requires an appreciable time for the energy set free from the condenser to be transformed into mechanical energy in the magnet, and when R_1 is large the back e.m.f. lasts for a very short period. The tripping action is thus not only dependent upon the rate of change of the current but also on the



[YARDLEY]

FIG. 7—280-VOLT, 1000-KW., 60-CYCLE COMMUTATING-POLE SYNCHRONOUS CONVERTER



[YARDLEY]

FIG. 10—TWO 750-VOLT, 60-CYCLE SYNCHRONOUS CONVERTERS CONNECTED IN SERIES

PLATE CXXI.
A. I. E. E.
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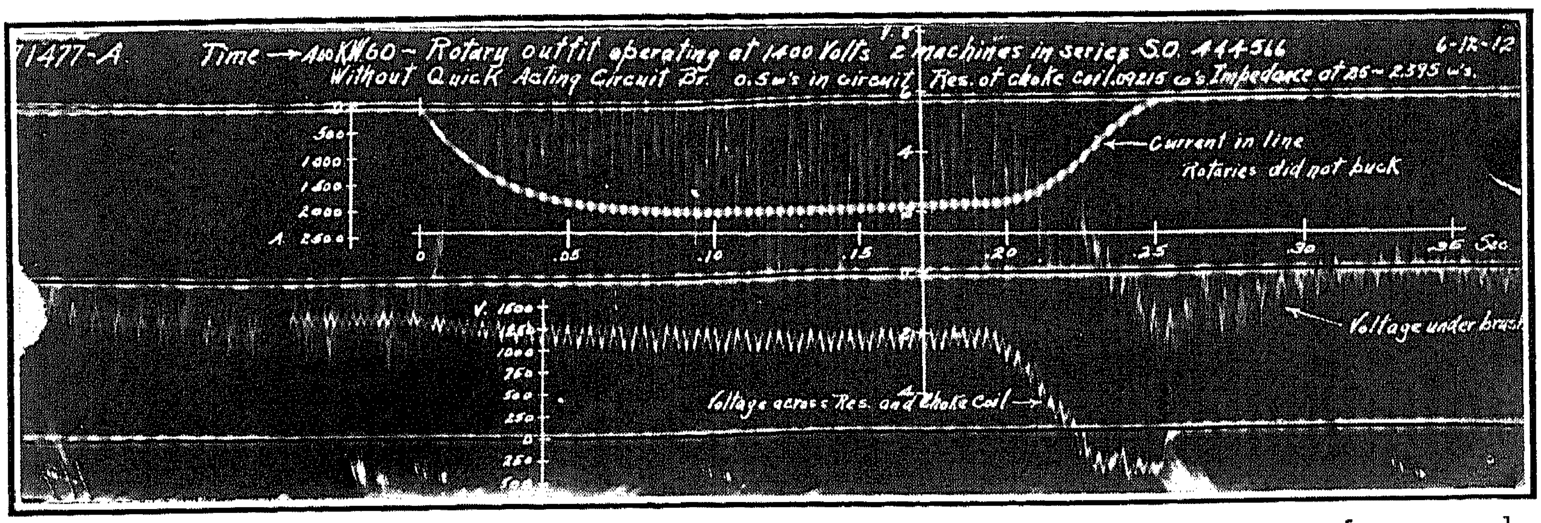

FIG. 12 [YARDLEY]

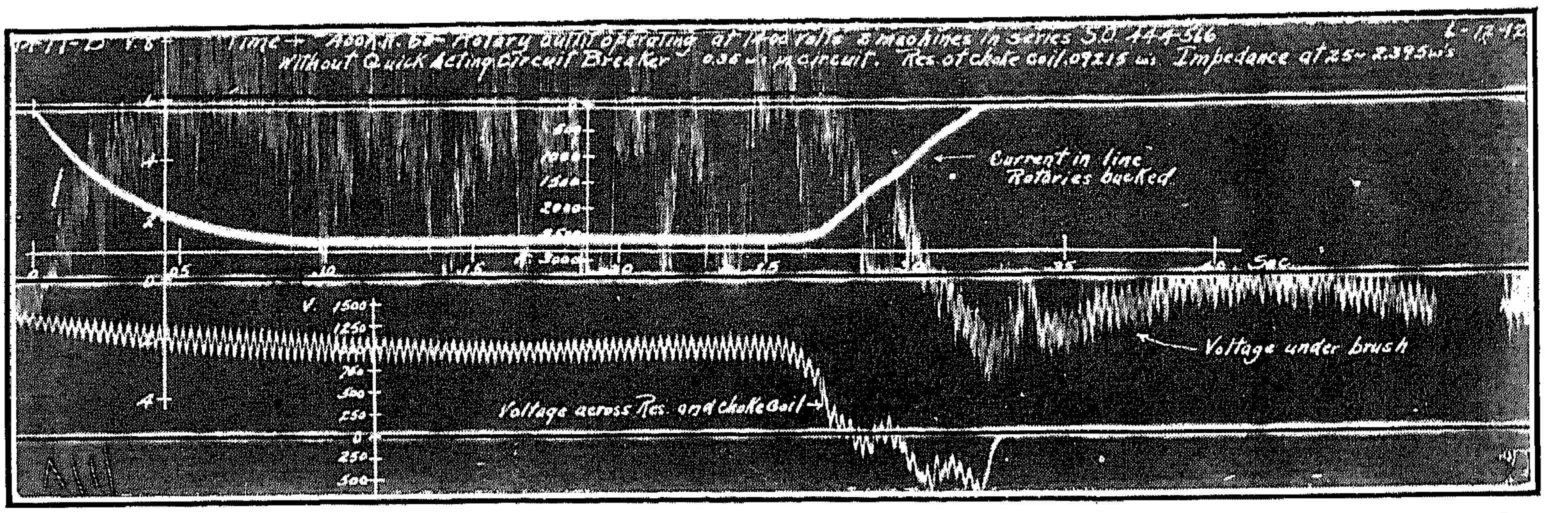

FIG. 13 [YARDLEY]

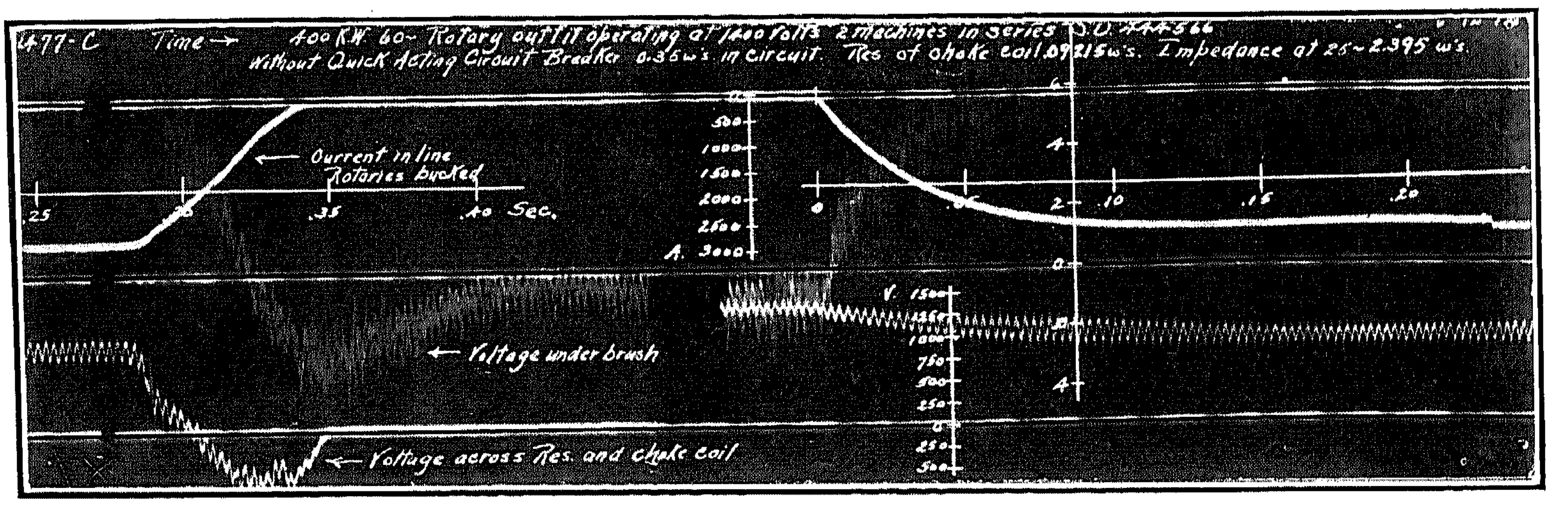

FIG. 14 [YARDLEY]

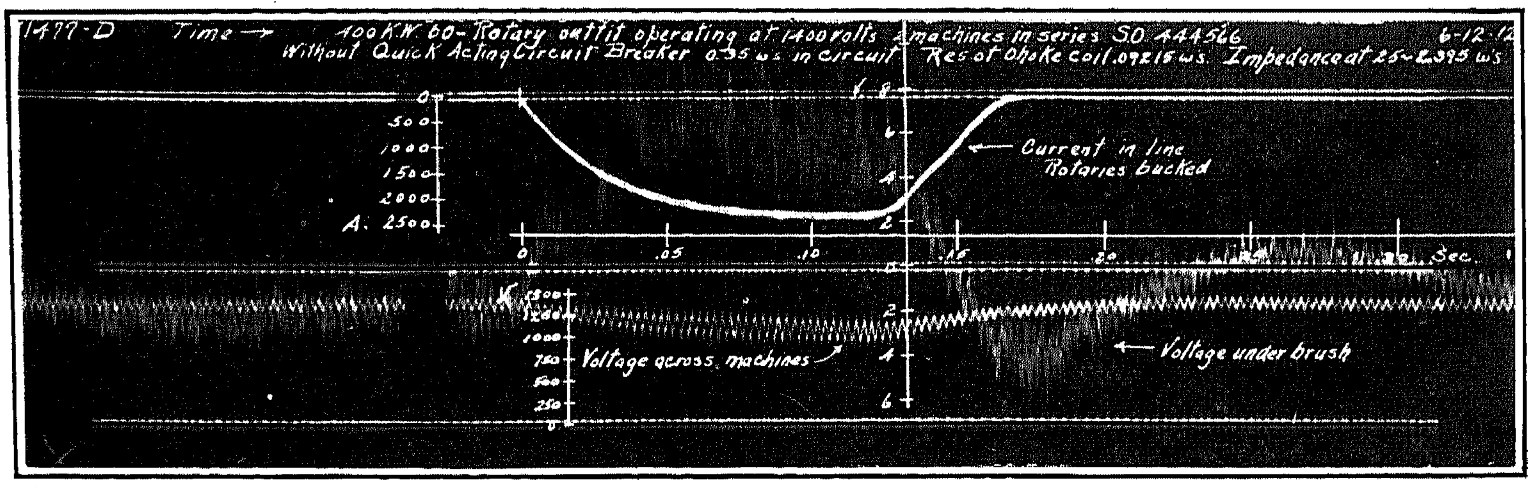

FIG. 15 [YARDLEY]

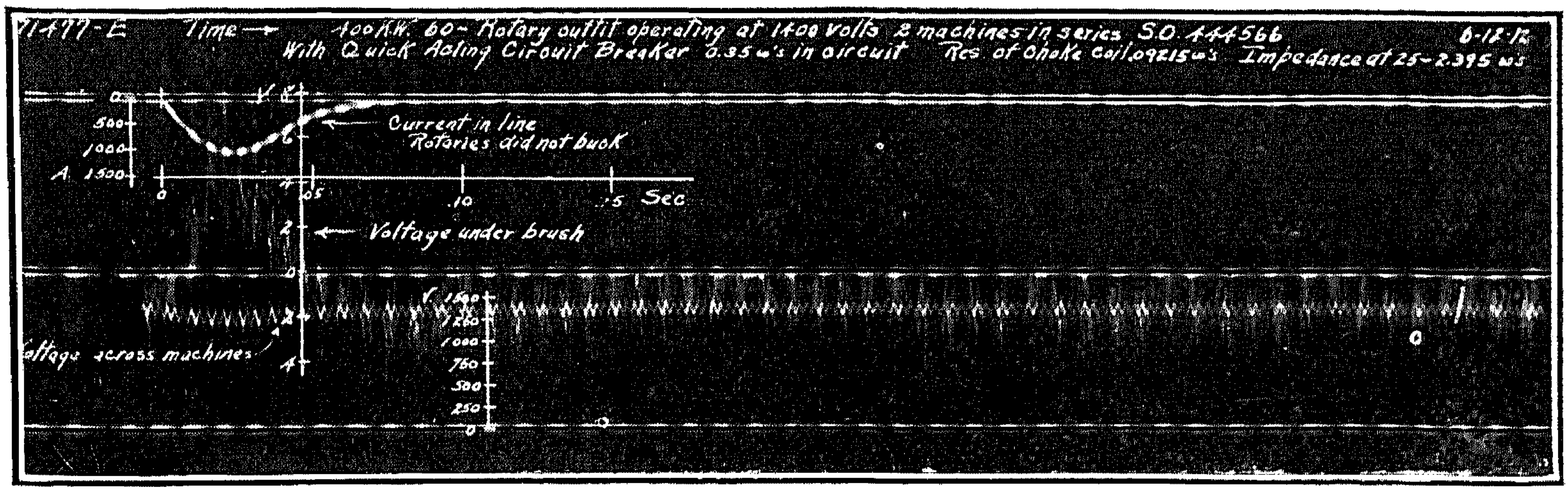

FIG. 16

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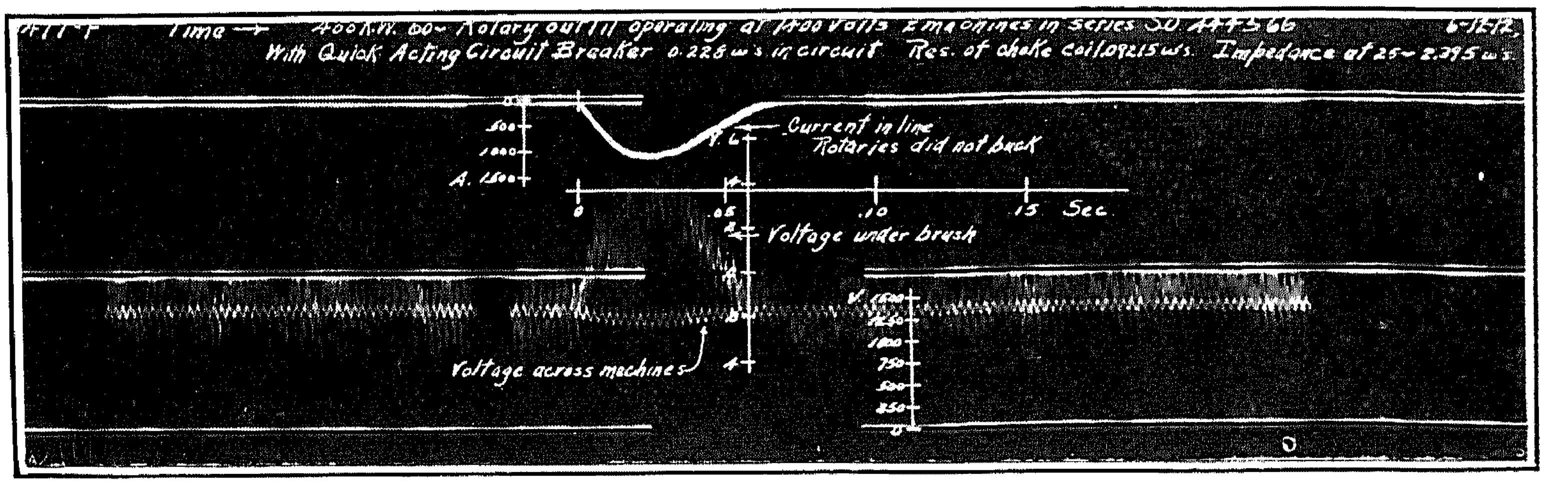

FIG. 17

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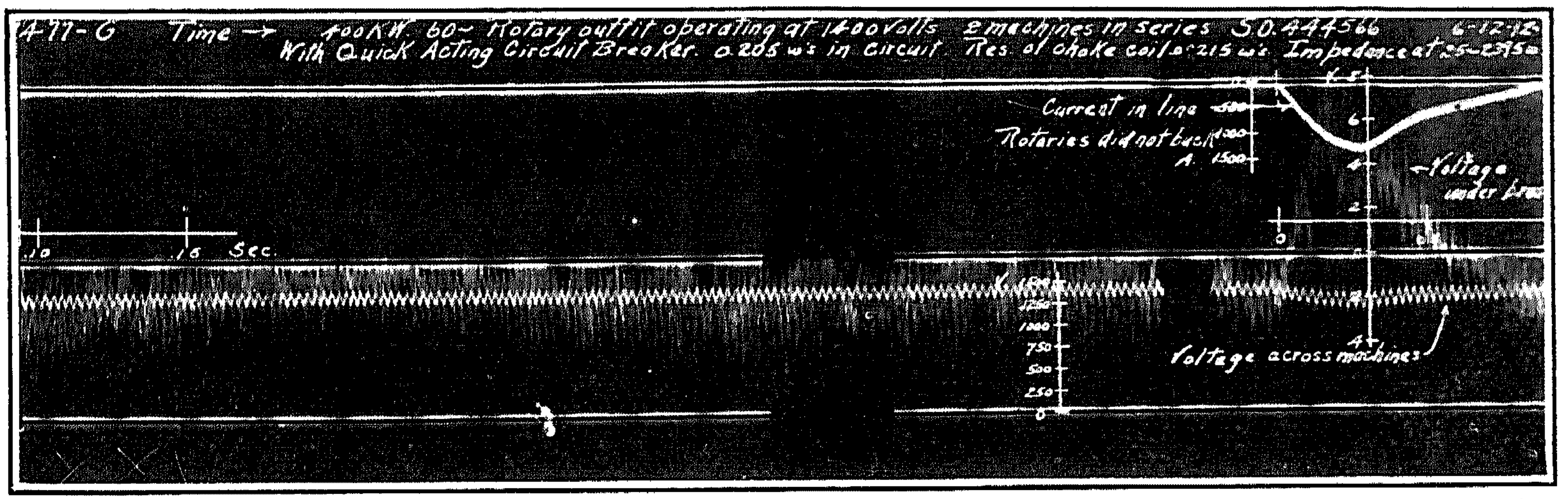

FIG. 18

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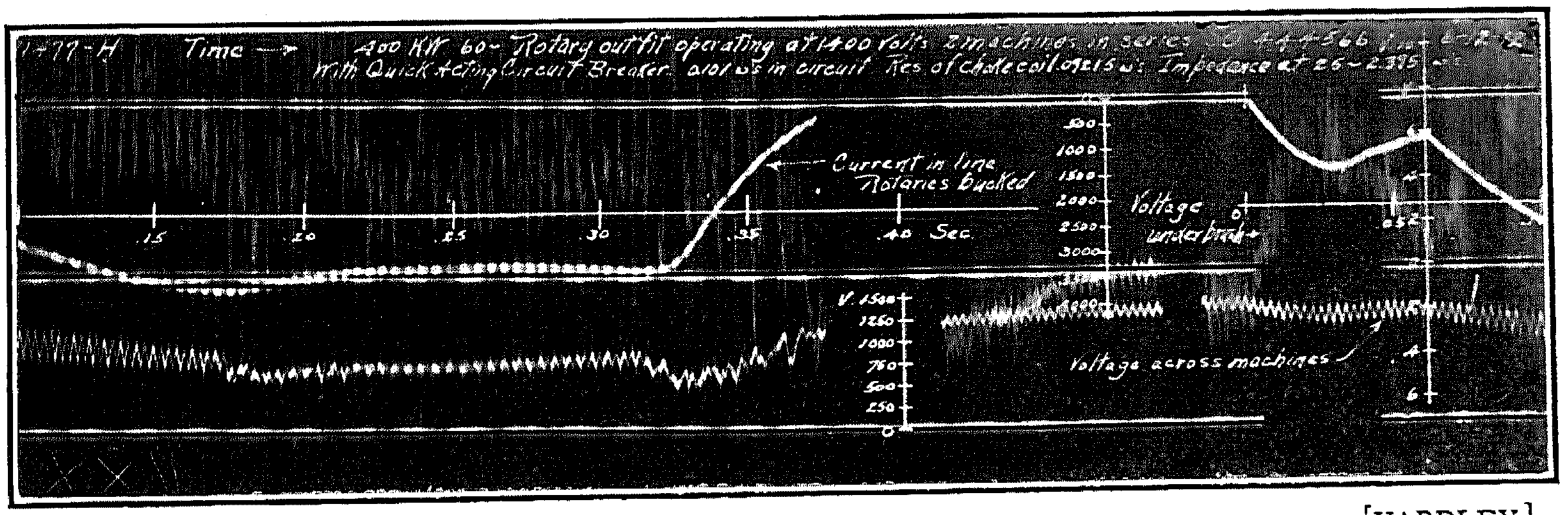


FIG. 19

[YARDLEY]

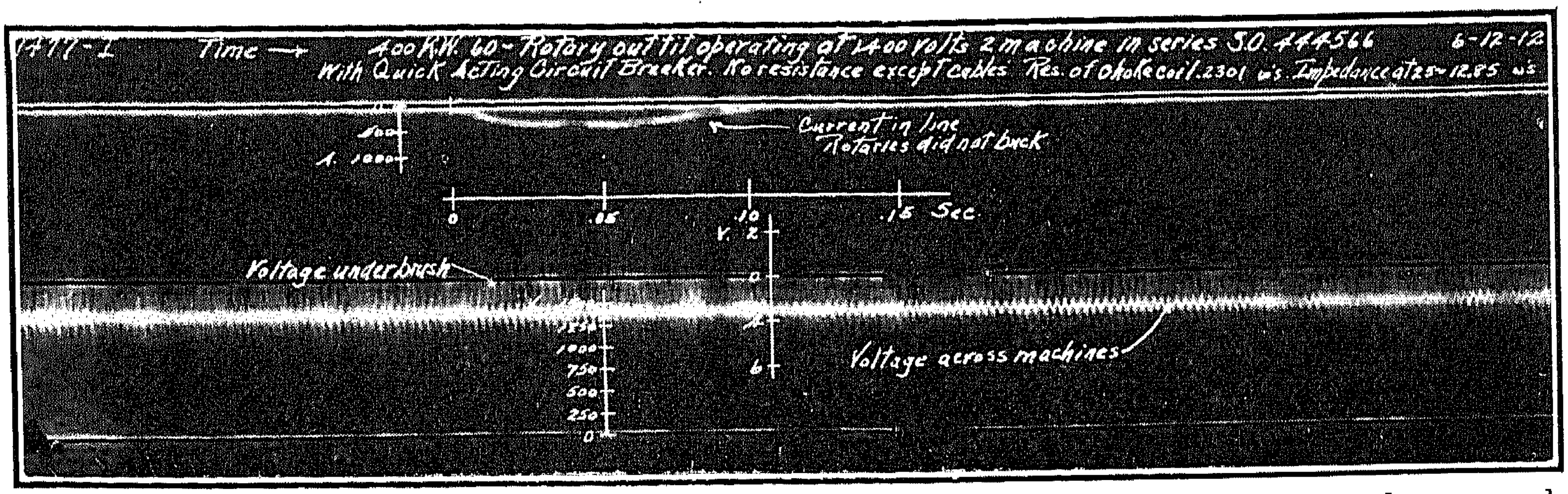


FIG. 20 [YARDLEY]

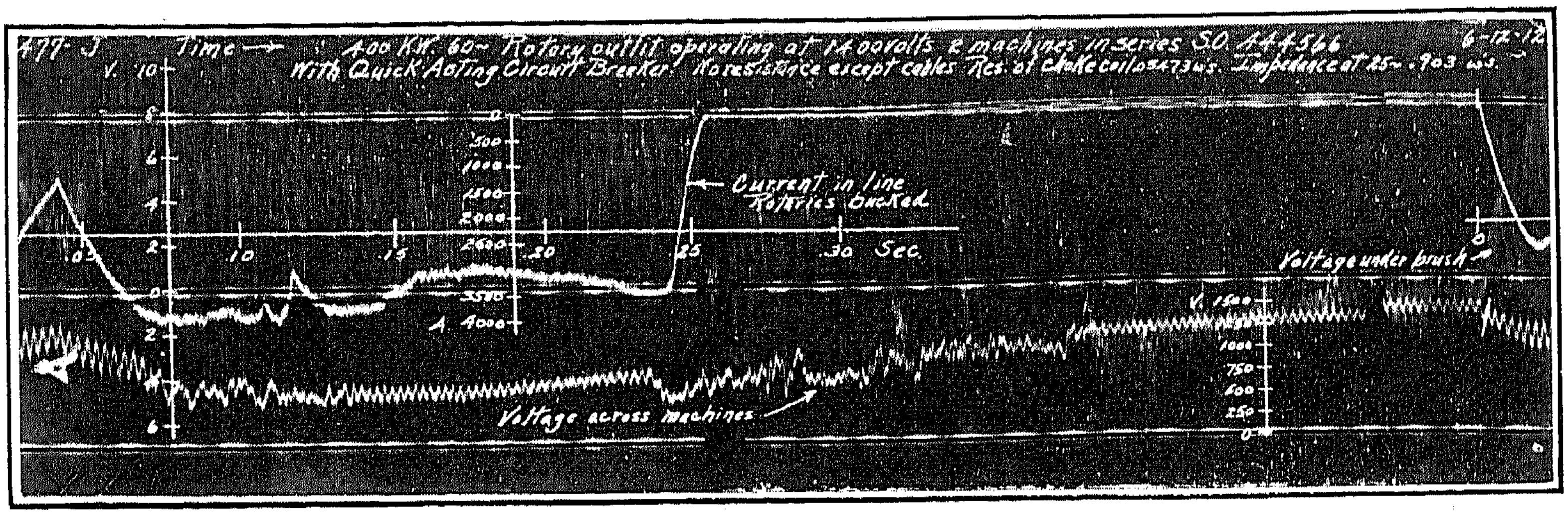


FIG. 21 [YARDLEY]

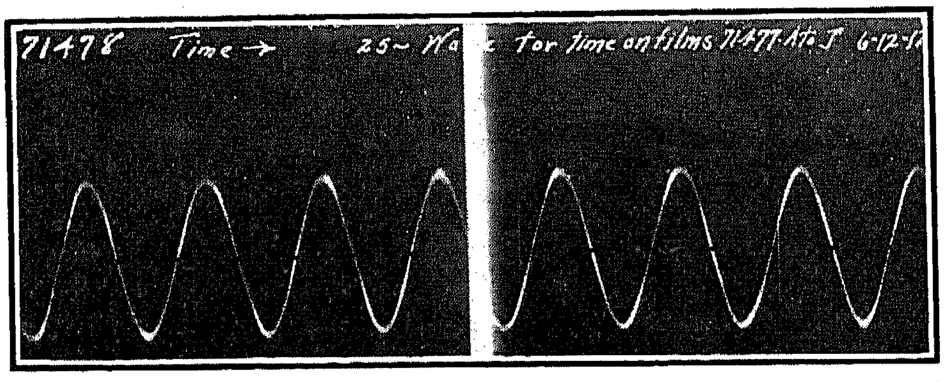


FIG. 22 [YARDLEY]

final value of the resistance. It may therefore be depended on to open the circuit only when the final value of the current would be such as to endanger the circuit.

For slowly varying currents, such as those due to the ordinary overloads, the regular overload tripping arrangement must be included in the breaker, as the condenser trip fails to operate under these conditions.

In case the current increases at such a rate that the ultimate value when the circuit breaker opens will be such as to endanger the circuit, additional inductance may be introduced in the circuit between the source of e.m.f. and the point at which the tripping gear is connected.

A series of tests was made to determine how severe a short circuit a synchronous converter would stand without flashing when protected by this quick-acting breaker and suitable operating reactance. The converter shown in Fig. 10 was used. This is a 1500-volt, 60-cycle set consisting of two 750-volt converters mounted on a common bed-plate and connected electrically in series. The armatures are mechanically separate, though a single bearing housing is used between them. The set is rated at 600 kw., 1500 volts, or 500 kw., 1250 volts, that is, it has a full-load current of 400 amperes. It is three-phase, with a speed of 1200 rev. per min. The oscillograms are marked 400 kw., though the machine will meet the higher ratings without exceeding standard temperature guarantees. The connections for test were made as per Fig. 11.

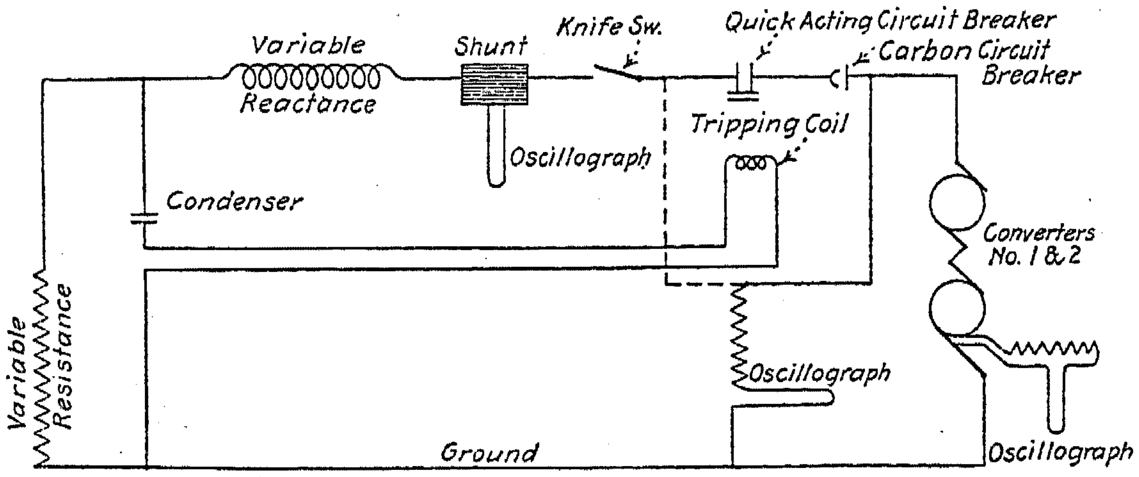


FIG. 11—SYNCHRONOUS CONVERTER WITH QUICK-ACTING BREAKER AND REACTANCE

The oscillograms are shown in Figs. 12 to 22, Fig. 22 simply giving the time for Figs. 12 to 21. It shows a 25-cycle wave taken with the film run at the same speed, and is of no other value. The d-c. circuit of the converter was closed by means of a knife switch as shown in Fig. 11, the load consisting of resistance which could be varied in amount. The reactor, of air-core type, was so constructed that its reactance could be varied by placing the sections in series or parallel.

In the first tests, as shown by Figs. 12 to 15, the quick-acting circuit breaker was omitted and the circuit was opened non-automatically by means of the carbon circuit breaker after a period long enough to determine whether the load itself would immediately result in flashing. For Figs. 12 to 14 one element of the oscillograph was connected as indicated by dotted lines in Fig. 11, to show the voltage across the resistor and choke coil. It will be observed from Fig. 12 that approximately 2100 amperes or 525 per cent normal load current was thrown on and tripped off this converter without flash-over. Figs. 13 and 14 show duplicate tests under heavier short-circuit conditions. The direct current rose to a steady value of 2600 amperes and the converter flashed when the circuit was tripped. Fig. 15 shows test under the same conditions except that the voltage element of the oscillograph was changed to the full line position in Fig. 11 so as to give the machine voltage. In these tests the final direct current was, of course, limited only by the total resistance in the d-c. circuit, although the effect of the reactor in retarding the rise and fall of the current is very noticeable from the films.

For the tests shown by Figs. 16 to 21, the quick-acting breaker was in circuit. The object of the reactor in connection with this breaker was to so affect the rate of increase of current that the breaker would be able to trip out before the current reached such a value as to cause flashing. Fig. 16 shows a test under the same short-circuit conditions as Fig. 15. Figs. 17 and 18 are with reduced resistance in the short-circuit path. As shown by Fig. 19, the resistance was then reduced to approximately 0.1 ohm. The quick-acting circuit breaker started to open the circuit and then arced across the terminals and short-circuited, so that the current—3500 amperes—was practically the same as though the quick-acting breaker had not opened at all. The quick-acting breaker was simply an experimental breaker and did not have the proper insulating clearances which would be given a commercial breaker to meet such conditions. The converter of course flashed over, as would be expected, when the circuit was finally tripped by hand. The next test, as shown by Fig. 20, was made with no resistance except that of the cables and the reactance coil, which latter amounted to 0.23 ohm, in the external circuit. The impedance was increased to 13 ohms. The last test, as shown by Fig. 21, was made with the choke coil resistance of 0.05473 ohm and the cable resistance only in the external circuit and the impedance reduced to 0.903 ohm. This test was made for the purpose of showing how quickly the current would rise under such a short-circuit condition. The breaker opened as in Fig. 19 but arced across terminals and short-circuited, causing a final flow of current of 3900 amperes. It is interesting to note that the converter carried this 975 per cent current load at approximately 700 volts without flash-over, although it of course at once flashed over when the load was tripped off.

These tests are described to establish the fact that, if a properly designed quick-acting circuit breaker be used, and the proper amount of reactance be placed in the d-c. circuit, it is impossible to flash a converter over, as the circuit breaker will trip out the circuit before the current approaches the tripping out flash-over value. As shown by Figs. 12 and 13, this flash-over value for this particular converter is somewhere between 2100 and 2600 amperes. It is interesting to mention that as far as this particular converter is concerned there is scarcely need of such protection under the particular test conditions. The tests were made one right after the other and whenever the converter flashed over the commutator and brushes were so slightly burned that it was unnecessary to do any work on them between tests.

DISCUSSION ON "PROTECTIVE REACTORS FOR FEEDER CIRCUITS OF LARGE CITY POWER SYSTEMS" (LYMAN, PERRY AND ROSSMAN) AND "USE OF REACTANCE WITH SYNCHRONOUS CONVERTERS" (YARDLEY), NEW YORK, OCTOBER 9, 1914.

D. B. Rushmore: It is very difficult to consider the subject of reactors for power stations or feeders without studying the apparatus, such as generators, transformers, oil switches, protecting apparatus, etc.

As a rule, electrical disturbances are due either to high currents, high voltages or high frequencies; and high frequencies have, as a rule, an indirect effect of producing high voltages, so we have simply high currents and high voltages to contend with.

The use of reactors as a protection against high voltages is well known, and, I take it, is rather outside of the subject of the papers tonight; so we come down to the use of reactors as protective devices against high currents, and this is a subject which is comparatively new.

Those who have been associated with the building of transformers, know it is only a very few years since competition was based on excellencies of regulation. The transformers that regulated 1½ per cent were supposed to be very much better than those which regulated 2½ per cent. Now, however, the customer frequently specifies that the transformers must contain six or eight per cent reactance and even higher.

In designing generators, transformers, and to some extent converters and other synchronous apparatus, if you design for commutation and heating there will be a natural reactance that will fit these conditions, and without an abnormal design you cannot vary these reactances beyond a certain point. It is therefore a question discussed in many cases as to how much internal and how much external reactance there shall be.

The use of reactors in power stations also involves a study of feeder reactors, because one is so dependent upon the other. The injurious effects which these reactors are supposed to protect against are, first, the incidental rush of current, which is destructive to the windings and brings tremendous mechanical forces to bear thereon. Secondly, there is the heating effect, and it has been necessary to investigate to some extent the time which apparatus will stand very abnormal heating conditions when there is practically no chance for the dissipation of heat, but simply its absorption in the material in which it is originally generated.

Reactance is an evil; it is a necessary evil in some cases, but what we want is a reactance which is only there when it is required; so if someone will invent a reactance which is not a reactance until it is wanted, we will be greatly helped. That is, a reactance which is very low until the current exceeds a certain amount, and then is automatically raised to a very high value.

Philip Torchio: We hear so much talk of reactance now, because we neglected to take into account its importance in the past. For instance, very few of us used to consider when we compared the breaking capacity of a switch whether the short circuit was on a 25-cycle generator, or a 60-cycle generator. Provided it was the same capacity generator, we would have expected that the short circuit effect would be the same. But it makes a large difference in a feeder short circuit whether the current is 25-cycle or 60-cycle. At 60 cycles the reactance of the feeder would be 2.4 times that at 25 cycles, and the effect of short circuit would therefore be very different in the two cases.

I think the authors have covered pretty fully the benefits and advantages obtained from the use of reactors on feeders. I wish to add a few statements which have been perhaps omitted. One is, that the energy loss in feeder reactors is extremely small, and amounts to less than 1/10 of one per cent on 60-cycle, and less than $\frac{1}{6}$ of one per cent on 25-cycle transmitted power for a $3\frac{1}{2}$ per cent reactance.

In addition to limiting the current flowing into a feeder short circuit, the feeder reactance further increases the continuity of supply by preventing the generator bus voltage from materially dropping. As an example: Assume the 150,000-kv-a. bus with 8 per cent generator reactance given in the paper, with 5000-kv-a. feeders having 3 per cent reactance. The maximum feeder short circuit would cause only a momentary 9 per cent drop in the bus voltage. This is very essential in holding all of the synchronous apparatus in step on the system.

In very large systems the question of limitation in rupturing capacity of oil switches is a burning question. In this respect a 2 per cent or 3 per cent limiting reactance on the feeders would ensure the opening of the feeder short circuit under all conditions, without the least strain on the switch, or interference with the rest of the service.

The New York lighting companies found from their experience that some of the few serious generating station troubles were occasioned by failures of high-voltage motors driving auxiliary apparatus like station exciters, etc.

Recognizing this fact, they were pioneers in the use of feeder reactors by equipping all of the feeders supplying generating station auxiliaries with reactors, which have proved to eliminate entirely all of the serious troubles from that source.

Fig. 1 gives an illustration of such an installation, showing three sets of 250-kw. 8000-volt motor-generator exciters, each equipped with 2.5-kv-a. reactors.

The first station designed and equipped for busbar reactors and feeder reactors is the 201st Street station of The United Electric Light & Power Company, having an ultimate capacity of 130,000 kw., 8000 volts, three-phase, 60 cycles. Between each two sections of buses there are installed 18 per cent reactors (based on 30,000 kv-a.), and on each 4000 kv-a. feeder $3\frac{1}{2}$ **per** cent reactors. The feeders are arranged in groups of two, each group being fed from a group switch. There are only two reactance coils for each feeder.

Fig. 2 shows one coil of one feeder in the front compartment, while the other coil is in the back compartment. In each of these compartments and on top of the existing coil there is a vacant space for the addition of a second coil for the second feeder not yet installed.

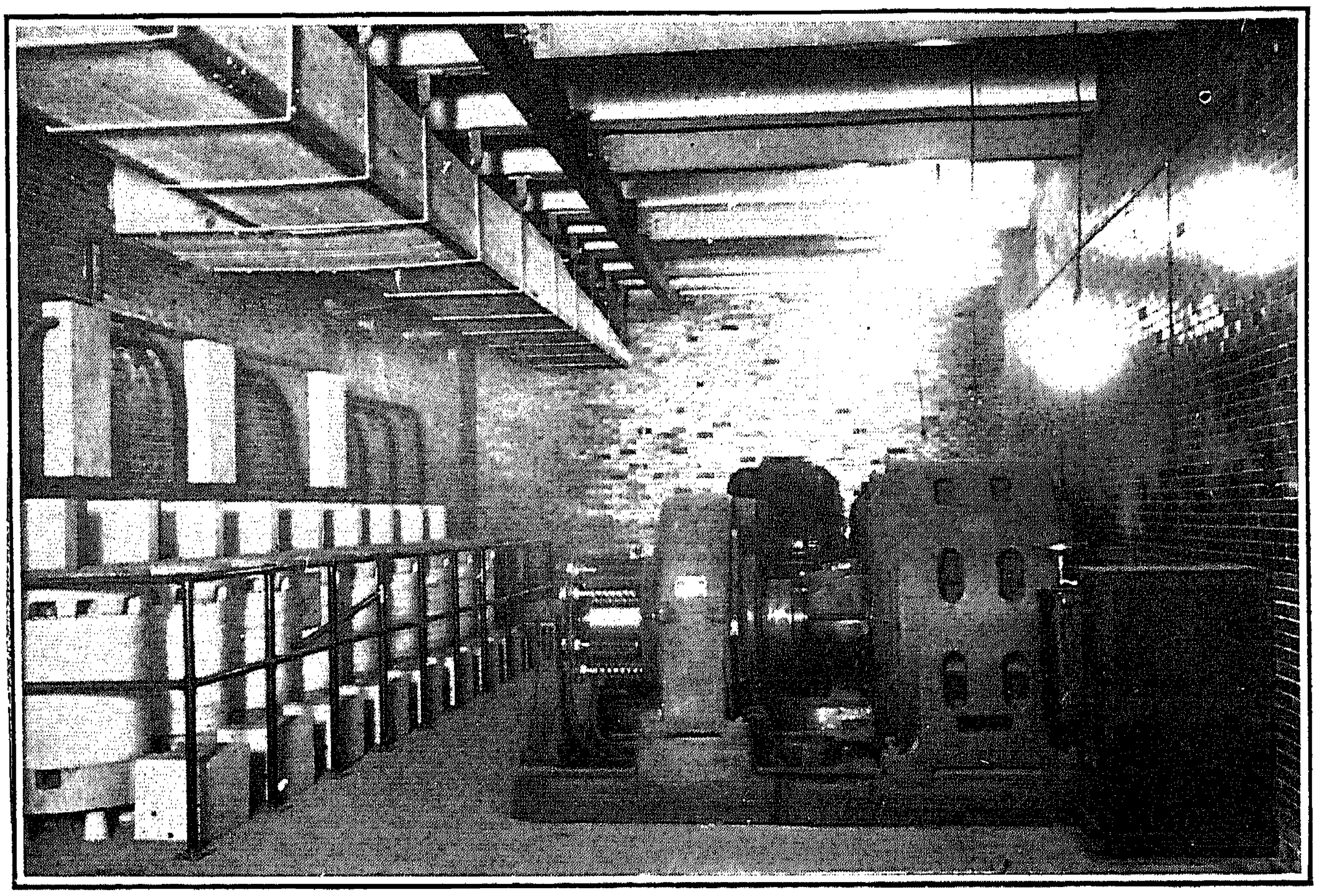
Fig. 3 shows a compartment with the double coil for the two feeders, both feeders of this group being already installed. On the right side are shown the terminals of the reactors through porcelain bushings.

Fig. 4 shows perhaps more in detail the construction of the feeder reactors and illustrates also the method of winding of the coil, which, after being saturated and baked, is placed in the holder with porcelain supports at top and bottom and sides, and ebonized asbestos board panel enclosures, for safety to apparatus and men.

In this connection I wish to lay stress upon the point of using insulated windings for the reactors. Coils with bare windings do not appear to me to be in keeping with the scrupulous separation by barriers and insulation of all high-tension conductors and wiring of a modern switchboard. Furthermore, I think that some insulation is necessary to protect the windings from foreign substances, vapors, accidental moisture and vermin. The difference in cost between bare windings and insulated windings is very trifling. The idea that bare windings can withstand higher temperature and therefore are safer is misleading, because it overlooks the fact that the protective reactance coils are always in circuit with other apparatus, like generator or transformer windings, cables and current transformers, all of which are insulated with fibrous materials and have less facilities to radiate heat than the reactance coils, and would burn out long before the insulation on the reactance coil would suffer.

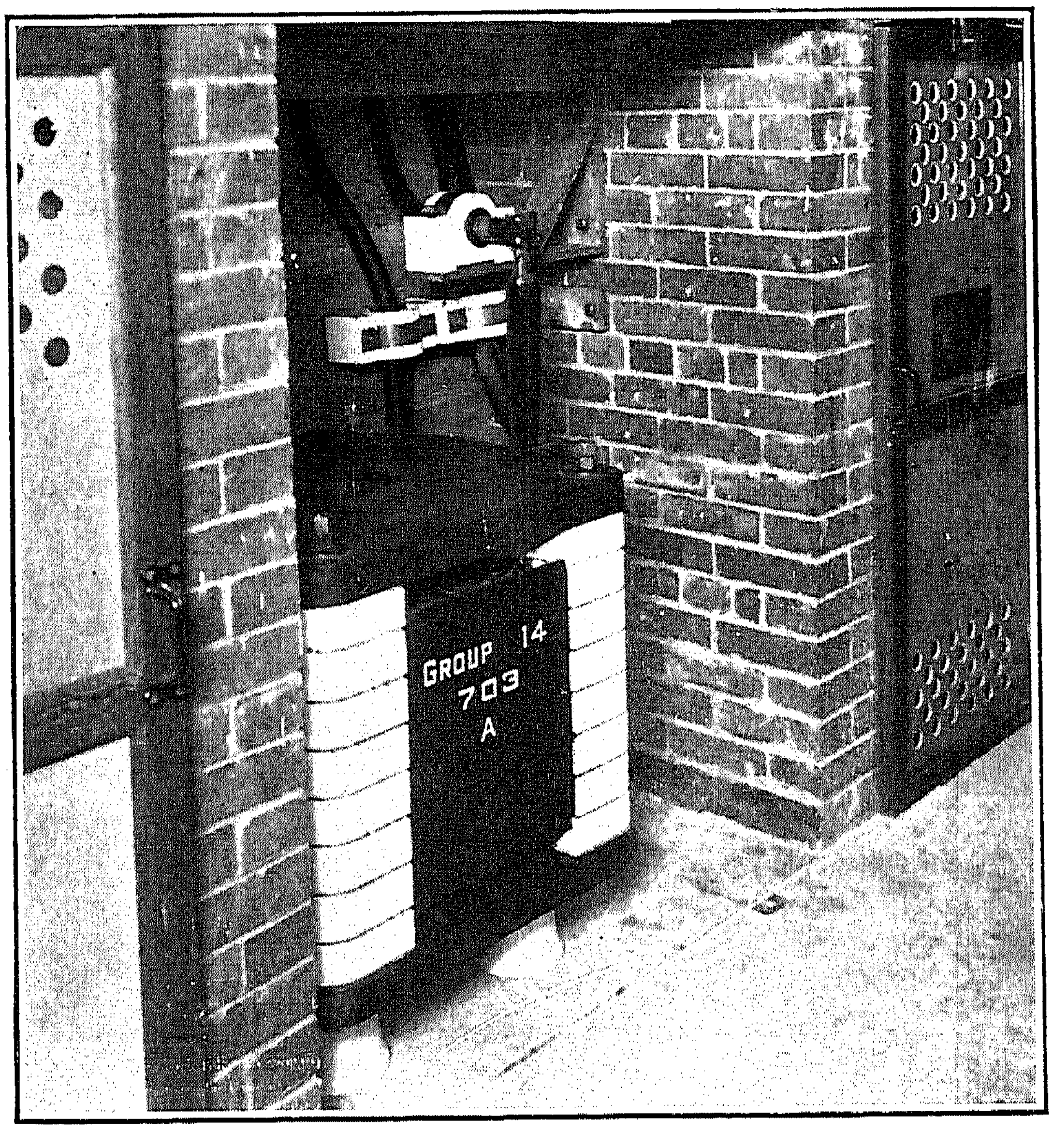
From an extensive experience with insulated-winding reactors under most diversified conditions in this country and abroad, there is not a single instance of failure. Furthermore, some of these reactors have operated for several seasons when covered with soot and dripping wet from rain and snow blown on them, under conditions where a bare winding would have undoubtedly failed.

H. W. Buck: This question of reactance is certainly very important in alternating-current circuits, but I do not think that we should allow ourselves to be led to believe that all alternating-current systems should have reactors installed upon them. Simplicity is an excellent engineering goal to steer for, and our alternating-current installations are already too complicated, and reactors still further increase it. The acute necessity for reactance has been brought to our attention within



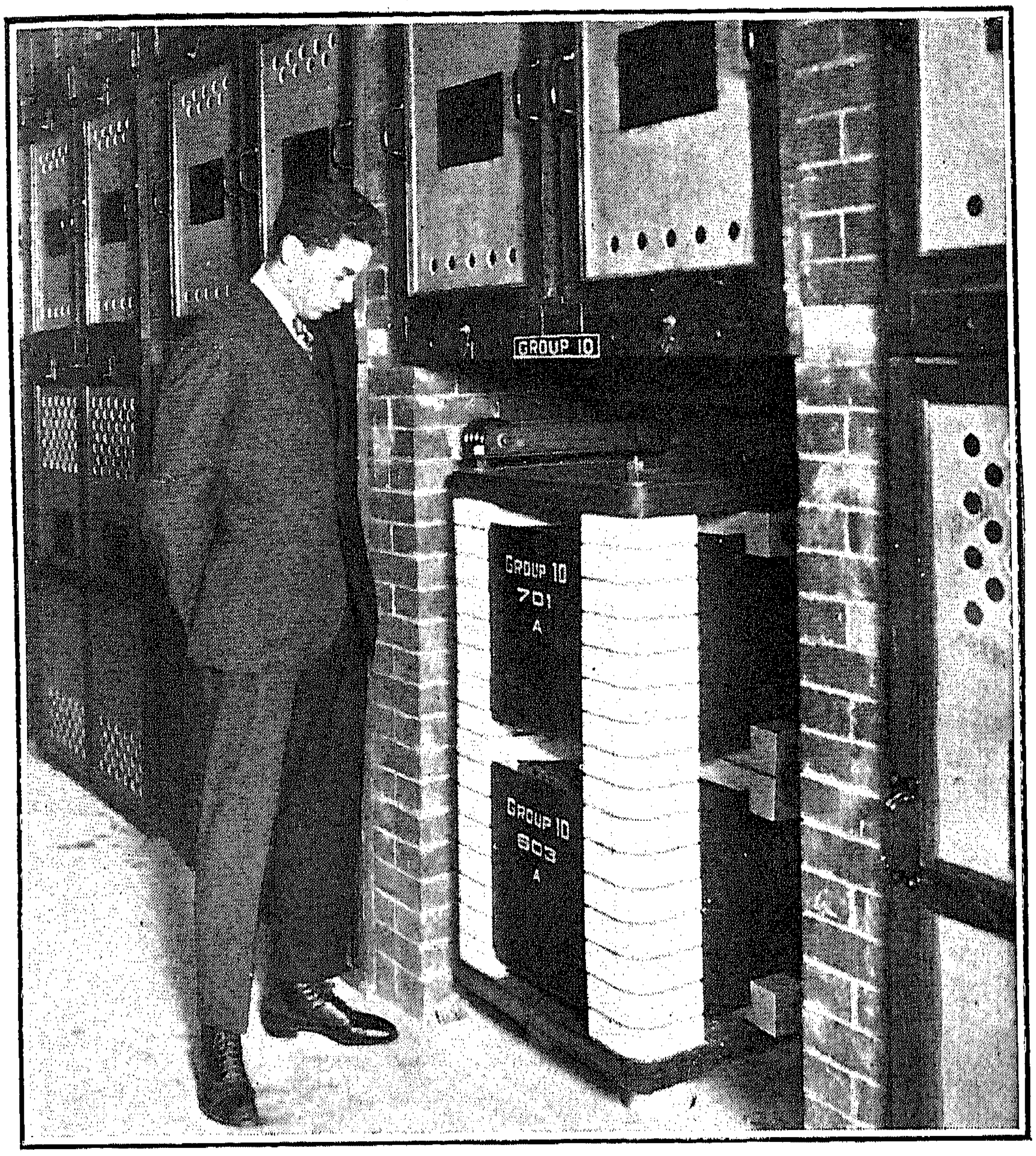
[TORCHIO]

FIG. 1



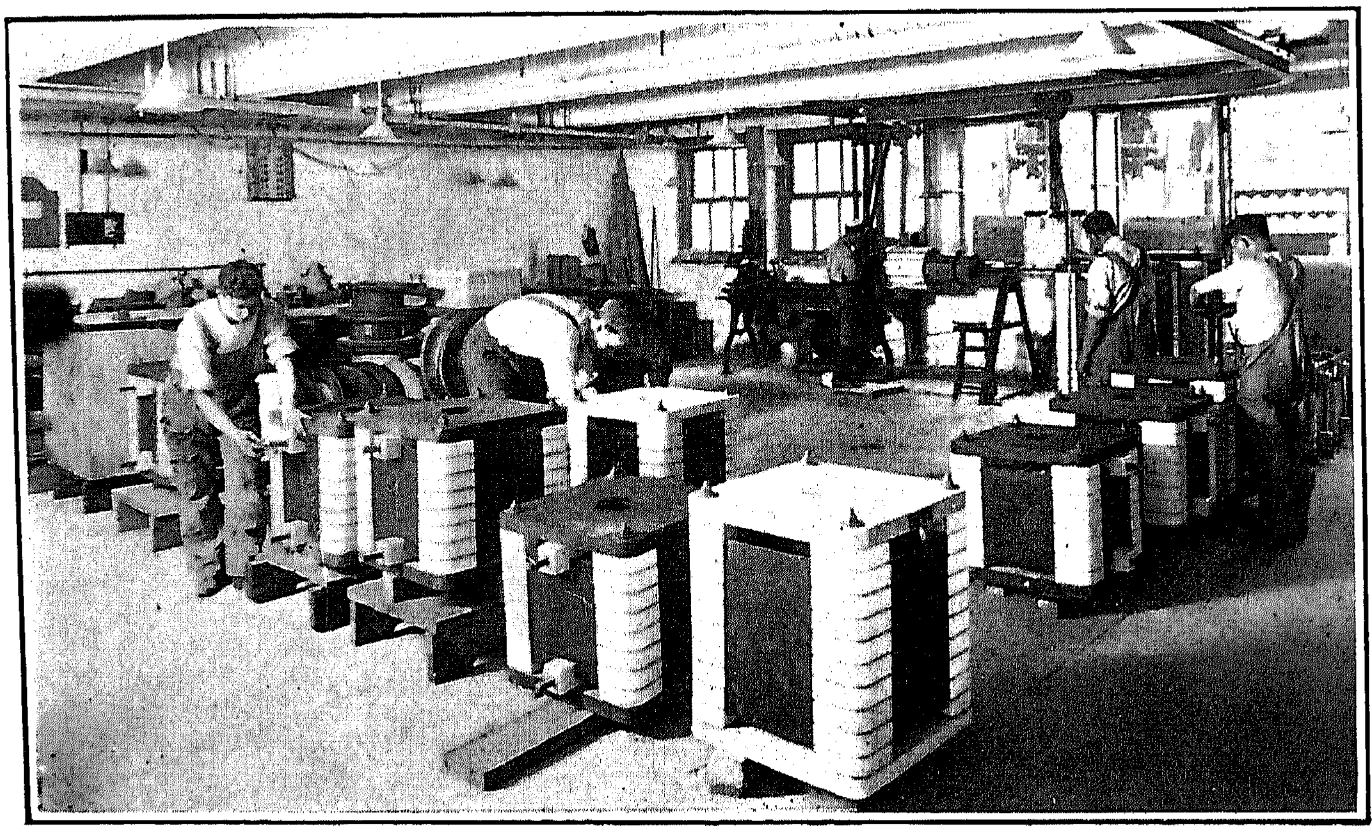
[TORCHIO]

FIG. 2



[TORCHIO]

FIG. 3



[TORCHIO]

FIG. 4

recent years through the development of such systems as that of the New York Edison Company and the Chicago Edison Company and others, where an enormous amount of power is concentrated in one generating station with the power transmitted over circuits of small inherent reactance, with the consumers located at comparatively short distances from the sources of generated power.

Here reactors are needed to improve the service and to preserve the integrity of the system against damage from abnormal magnetic forces. The enormous momentary flow of current in an alternating-current generator under short circuit, possibly ten or fifteen times what it is at the end of a few seconds, causes magnetic effects which are irresistible with a number of generators connected to the busbars and with possibilities for destruction in the stations which are very great.

Many instances of such destruction from magnetic forces have been noted and some which I have seen are as follows:

In one case a short circuit took place near a large power house. The busbars which were installed inside of a modern brick structure were blown out by magnetic repulsion through the brick of the surrounding structure, the busbar structure itself was demolished, and the copper of the busbar was blown 40 ft. or 50 ft. from its original location.

In another case, about 24 one-million-circular-mil single-conductor cables were racked on the wall of a run-way about 15 ft. wide. A short circuit took place in a manhole near the power house, with the result that every cable in the run-way was torn from the cast iron racks on which they were supported and hurled across the run-way, damaging the masonry on the opposite side.

A third case resulted in a short circuit of a power house of about 60,000 kw. normal capacity. The feeders through which the short-circuit current flowed were of ordinary three-conductor type, lead-covered. Under the magnetic stress prevailing several of the cables exploded, blowing the lead covering to pieces and demolishing sections of the eight-duct conduit in which they were installed.

I mention these instances to show the possibilities of the enormous magnetic mechanical forces which are available momentarily under short circuits from the large power houses, and the necessity of limiting the maximum flow of current under conditions of short circuit by the installation of reactors.

On long distance transmission systems where an overhead line intervenes between the generating station and the point where the power is used, reactance is not needed to prevent destruction at the receiving end, as the line itself necessarily has such high reactance that it automatically limits the flow of current at the terminus of the line to a safe maximum amount. Distribution systems, therefore, which are fed by long-distance transmission need reactors only for the purpose, as stated in the paper, of controlling the regulation and for limiting the voltage disturbances on the system.

There is an important use of reactors on long-transmission trunk lines where a tap line is connected to the main trunk line, over which a comparatively small amount of power is supplied. Here it may be necessary to limit the amount of current which can flow over the branch line and so prevent its being a menace to the service on the main line. By installing a 5 per cent or 10 per cent reactor in the branch line, the service over the main line is not interrupted, and the effect of short circuit on the branch line is practically negligible to the trunk line service.

It is unquestionably desirable to install reactance coils on such large systems as that of the New York Edison Company to prevent damage from magnetic forces where the service is through three-conductor underground cables of small inherent reactance, where the maximum flow of current is limited only by the ohmic resistance of the circuit.

H. R. Summerhayes: Mr. Buck has just emphasized the necessity for simplicity in alternating-current systems. To my mind we should aim for simplicity in operation, and possibly we may accomplish that by the addition of apparatus in the form of reactors.

In Mr. Yardley's paper it was pointed out that on the Edison d-c. systems of the larger size, in which the whole network is connected in multiple, troubles are local, and they burn themselves out and do not result in a shut-down of the whole, or even of a large portion of the system. In fact, it is seldom that even the synchronous converter is shut down from these short circuits.

I believe the alternating-current systems are tending toward the same result. At present most of the large alternating-current systems are connected with radial feeders; that is, the feeders are not interconnected. Experience has shown that trouble will result if the feeders are interconnected in order to use the copper to the best advantage.

I believe that with the use of reactance in the proper localities, and the development of relays that has taken place, it will soon be possible to interconnect these systems and use the copper to better advantage; and that the operation will be similar to that of the direct-current system, in that the trouble will be localized.

One point brought out in the paper on feeder reactors, is that the busbar reactors must also be used, owing to the possibility of trouble in the station itself. That I think is a very important point.

There are other methods of using busbar reactors than simply connecting them between the sections. Some of the more recent ideas involve dividing large stations into one section for each generator, and not connecting those sections directly through reactors, but connecting each section through reactors to a sort of tie bus. This I think is a considerable improvement over older systems.

Mr. Lyman concludes that it would be desirable for many reasons to operate feeders in parallel at their substation ends, but such operation tends to increase greatly the kv-a. flowing into a feeder short circuit and to cause other feeders besides the one affected to trip out when overload relays with the usual settings are used. I would suggest that this conclusion does not apply to all cases. The development in relays makes it possible to operate the switches selectively even where the kv-a. values at short circuit are very high. There are some cases, for instance, where it is sufficient to install reverse-power relays at the substation ends of the feeders and selective overload relays at the generating station ends. In other cases different expedients may be necessary. Generally the addition of feeder reactors makes it easier to make the operation of the relays selective.

Mr. Torchio invited discussion on the matter of insulation of reactors. Of course the great advantage of using insulation is that it makes the reactance compact, saving space in the station where space is of importance. The dimensions are reduced, as you do not have to allow such great distances between conductors to prevent surface leakage. On the other hand, the insulation on the conductors introduces a comparatively large amount of inflammable material at a point where it is exposed to the greatest amount of heat; that is, it is right in contact with the conductor, and all the heat must go out through that insulation. In case of weakness at the time of short circuit when the voltage across the reactance is high, a puncture or local flash-over might cause a considerable fire.

Therefore, I believe that insulation on the conductors should be avoided as a rule and used only where special conditions such as high working voltage, large number of turns or limited space for installation make a reactor with bare conductors impracticable.

J. J. Frank: In Mr. Yardley's paper reference is made to an automatic switch operating as a protective device. I question the ultimate value of such a mechanical device as an automatic protection in comparison with the value of the absolutely magnetic device found in these current-limiting reactors.

The controlling feature in the design of current-limiting reactors should be their function as a protection to generators, busbars, and feeder circuits. Every other feature in details of construction should be secondary to this dominating one. Both the mechanical and electrical designs may be widely different on reactors protecting generators and busbars, from those to protect high-voltage circuits, as referred to by Mr. Buck.

N. W. Storer: Mr. Rushmore has propounded a conundrum. He believes thoroughly in a larger reactance to keep down the violence of short circuits, as most of us now do, but he wants reactance that is reactance only when it is needed. The conundrum then is, "When is reactance not reactance?" The answer is, "When it is short-circuited," and Mr. Yardley's paper has shown us how to secure this kind of reactance. One of the most noteworthy points in his paper is his reference to the tests of a quick-acting circuit breaker. I believe that the use of this circuit breaker to short-circuit a large part of the external reactance in the circuit will give just the combination that is desired. A certain amount of reactance must be in the circuit all the time, but given a quick-acting breaker such as described we can get all the benefit of a large reactance without its bad effects.

George T. Hanchett: When extraneous reactance was first introduced as a protective device, it always appeared to me as a piece of patch-work to cover up some of our previous mistakes. As Mr. Rushmore says, early specifications called for regulation par excellence, and having obtained, at great expense, rigidly constant potentials, we begin to counteract these by installing at further expense protective reactance.

We seem to have forgotten that it is very easy to build a transformer or generator of more open design by using larger clearances which will facilitate insulation and ventilation and reduce cost. In the case of feeders, particularly where it is desirable to interlock them, trouble flows from feeder to feeder through these interconnections which may well be reactors.

I was visiting the plant of a large transformer company a few days ago and was impressed to observe the tendency to insert magnetic leakage plates in transformers. These facts should be seriously considered when contemplating large reactances for the protection of large generators or transformers. With existing closely designed equipments, reactors are absolutely necessary.

Carl J. Fechheimer: The statement has been frequently made that iron in reactance coils is undesirable, as it saturates, such saturation occurring at just the wrong time unless a very large amount of iron is employed. The purpose of reactance coils is to prevent a prohibitively large current flowing; and if the value of reactance decreases as the currents increase in magnitude, due to the iron saturating, it fails of its purpose. Therefore, I also believe that in transformers, to which reference has been made, the same effect will come in. Similarly in the construction of generators we should not count on the effect of iron for increasing the reactance, trusting that thereby the great rush of current will be prevented.

It is interesting to note that the magnitude of the current which flows at the first instant on short circuit does not depend only upon the voltage induced just before the short circuit occurs and upon the total reactance in the circuit, but it is also affected somewhat by the point of the wave at the instant that the short circuit occurs. Therefore it is frequently a mistake to say that a certain percentage of reactance will permit a definite current to flow on short circuit, unless one also considers the point of wave. This was brought up in a paper by Mr. A. B. Field read before this Institute.*

The question of the point of wave as well as that of the saturation in the circuit brings up the question: What is the effective internal reactance on short circuit? It is evidently a rather difficult matter to determine and it may be well for us in the Institute to decide upon some method of estimating what value should be considered correct. There may be other minor effects which influence this rush of current, such as leakage fields from other phases as well as the phase under consideration. It is my belief, however, that we can approach nearest to the correct value of effective reactance by measuring the reactance with the rotor removed—in the case of a star-connected stator, between neutral and terminal; with delta connection, with current in one leg only of the delta; and in the case of two-phase, across one of the phases. If, however, partly closed slots or equivalent thereof are employed, the effects of saturation cannot be neglected, and this makes it practically impossible to measure directly the reactance with this or other forms of construction which involve leakage paths that may saturate.

I would like to call your attention to the marked tendency that is at present evidenced toward securing high internal reactance, especially in large generators. Large reactance is usually obtained by the use of as large a number of turns in the stator as possible. This may be carried so far that the most economical design is not the one that is adopted. The most economical design would be that which would give the cheapest machine insofar as the relative proportions of copper and iron are concerned. One often has the idea that the larger the number of turns (the smaller the flux) the cheaper will be the machine. This is not necessarily so. In these machines it may be necessary, in order to increase the reactance by increasing the number of turns, to increase the cost. It is at times essential to use very deep slots and to laminate the conductors very carefully in order to prevent large eddy current losses.

Let us consider what are the leakage fields in the generator which are effective as reactance, it being understood that the reactance is that quantity which if divided into the electromotive force will give the current which will flow, the effect of resistance being negligible. These leakage fluxes are those which cross the slots, those which pass from tooth to tooth through the air above the slot, and those which interlink with the stator end connections. Any leakage fields from the rotor are of little or no influence. The effect of the presence of the rotor is in most generators of very small influence; any fluxes which pass from the stator through the air gap into the face of the rotor and back into the stator usually must cross the double air gap, which introduces very high reluctance.

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*TRANSACTIONS A. I. E. E., 1912, Vol. XXXI, Part II, page 1645.

When a short circuit occurs on the alternator the tendency of the armature reaction is to wipe out the field. This tendency to cause the flux to die down induces in the field winding and in all other closed circuits in the rotor, electromotive forces which cause currents to flow, which in turn tend to prevent the dying down of the flux. In the case of the field circuit this current flows back through the exciter armature. There is therefore a tendency for substantially the same electromotive force to be generated in the stator conductors at the first instant after as before the short circuit occurs. The current that flows is that electromotive force divided by the reactance.

One is liable to infer, since the reactance of a machine with a large air gap is usually less than that of a machine with a smaller air gap, that this difference is due to differences in leakage fluxes which penetrate the rotor. We wish to point out that this conclusion is not correct. It is well known that the armature reaction of the machine is nearly proportional to the pole pitch and that the air gap is proportional to the armature reaction and hence to the pole pitch also. If the pole pitch is large, corresponding to a high-speed machine, the number of turns in the stator is also small, which means that the reactance is low. Hence low reactance generally accompanies large air gaps.

Mr. Woodward: Is there any circuit breaker developed which will open a circuit in 0.01 of a second? The damage is done in the first one-half cycle, and the circuit breaker would have to operate in 0.01 of a second. We can cut off that portion of the relay curve which is not selective, and reactance is a big factor in that way.

Mr. Howard: I note on Fig. 11 of Mr. Yardley's paper, that there is another circuit breaker in connection with that quick-acting circuit breaker. Does this quick-acting circuit breaker require one more, or is this merely a test condition?

Philip Torchio: I will say a word in explanation of my recommendation of insulating the windings of reactors. I do not have reference to any specific design in any way. I said, take the reactors as you build them now, but on the windings put on a light insulation. I am not recommending this to provide against the rises of potential; I assume that that has been taken care of in the design; my idea is to bring up the point of having some covering as a protection against dust and foreign objects.

I consider that essential, as in stations where we put in busbars and leads separated by brick compartments, we should not connect bare coils without separation between the windings, or something to prevent accidental contact causing short circuit.

Mr. Burnham: Several years ago I conducted a number of tests similar to those described in Mr. Yardley's paper, to determine the use of reactance for protecting synchronous converters. The results of these tests seemed to point only to one solution, and that was the availability of the quick-acting cir-

Another statement made is that, "with considerable series field and unsaturated reactance, a converter would continue to take on load owing to its approximate straight-line rising voltage characteristics." An unsaturated reactance would give a greater tendency for it to bend downward, rather than to go in a straight line. This is due to the increasing proportion of the energy current to the wattless current, which bends the converter voltage out of phase with the line voltage, and reduces it in value.

Another statement is, "The drooping characteristic on overload is obtained by employing a saturating iron core reactance." I believe the reference is true, that you get greater drop if you use a reactance that does not saturate. The smaller the reactance the flatter the regulation curve.

J. L. McK. Yardley: The first question was in regard to the possibility of building a quick-acting circuit breaker which would operate in 0.01 second. If you will refer to Figs. 16 to 19, you will note that the time is given and that this particular circuit breaker operated within 0.015 second. I believe it is only a matter of closer adjustment to reduce the time to less than 0.01 second. In fact, I understand later tests show such to be the case. This breaker of Messrs. Fortescue and Mahoney is really so unusual as to deserve a paper devoted entirely or primarily to itself.

In regard to the second circuit breaker shown in Fig. 11, of the ordinary carbon break type of construction, it was desired to secure a comparison between the results obtainable with the two types of circuit breakers. Figs. 12 to 15 should be compared with Figs. 16 to 19. For convenience, only, both breakers are shown in Fig. 11.

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Another statement made is that, "with considerable series field and unsaturated reactance, a converter would continue to take on load owing to its approximate straight-line rising voltage characteristics." An unsaturated reactance would give a greater tendency for it to bend downward, rather than to go in a straight line. This is due to the increasing proportion of the energy current to the wattless current, which bends the converter voltage out of phase with the line voltage, and reduces it in value.

Another statement is, "The drooping characteristic on overload is obtained by employing a saturating iron core reactance." I believe the reference is true, that you get greater drop if you use a reactance that does not saturate. The smaller the reactance the flatter the regulation curve.

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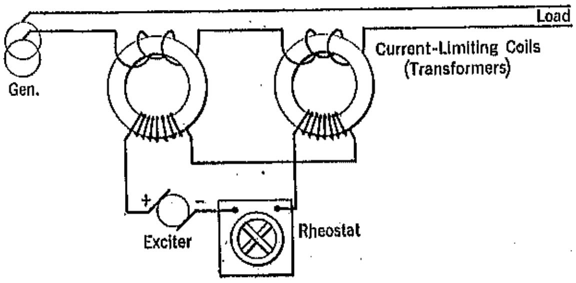
I don't exactly understand Mr. Burnham's objections to other parts of the paper. I believe it is common knowledge that the voltage regulation of a shunt-wound converter is better if the reactance in this a-c. circuit saturates as the load increases, than if it does not saturate, and that the reverse is true in the case of the compound-wound converter, the series field of which has not been too heavily shunted.

Before finishing, I desire to call attention to what seems to me the most obvious conclusion to be derived from the tests I have described. I think they point to one particular combination of a resistor, a reactor and a quick-acting circuit breaker which could be applied as a protection to both service and apparatus for the case of sudden excessive overloads equally well in any one of the three classes of synchronous converter installations. I refer to such a combination located in the d-c. circuit from the converter in which the resistor and quick-acting circuit breaker are in parallel electrical relationship with one another and in series relationship with the reactor. By properly varying the amounts of resistance and reactance, and also the amount of electrostatic capacity in the condenser operating the tripping device of the quick-acting circuit breaker, any predetermined sudden overload may be protected against. I have already recommended such equipment for one or two installations of converters where flash-overs have occurred due to sudden excessive overloads or short circuits; but so far as I know this arrangement has not, as yet, given a practical demonstration of its worth. It is apparent that the reactor in the d-c. circuit is no protection against an excessive overload gradually accumulated. It is further obvious that to be completely protected against an excessive overload, gradually as well as suddenly attained, a reactor must also be placed in the a-c. supply circuit. A careful analysis of the operating conditions, I believe, will always show that any desired degree of protection may be attained; but it will usually show that complete and absolute protection is not warranted or even desirable. It will show in many cases that the degree of partial protection suggested in my paper for the different classes of synchronous converter installations is a matter of economy and well worth attaining.

John B. Taylor (by letter): Protective reactors have a voltage across terminals varying from zero at no load to approximately 58 per cent of line voltage under short-circuit conditions. This " drop " in the coil disturbs the voltage regulation by a greater or lesser amount, depending on the power factor of the load, and under the most favorable conditions is a detriment.

Accordingly, coils without iron cores are used so that the coil-drop under usual running conditions will not be an abnormally large part of the total drop when short circuit occurs. Iron is omitted for the well-known fact that its permeability falls off with increasing magnetic flux density—in other words, it becomes saturated.

As there is no known material with magnetic characteristics reversed from those of iron, *i. e.*, increasing permeability with increasing density, the air-coil with straight-line characteristic, through having uniform permeability, is preferred. It is possible, however, to arrange matters, using iron itself as core, so that the desirable reversed characteristics result. This is accomplished by having the iron core saturated independently of the alternating-current circuit which the coil is to limit. If the core is completely saturated no flux change will follow the alternating current unless this has sufficient number of ampere-turns to overcome those above the saturation point in the auxiliary exciting circuit.



The accompanying diagram will make the arrangement clear. For simplicity, a single-phase instead of a three-phase circuit is shown. Two coils which are practically standard transformers are connected so that the direct-current saturating circuit does not form a short-circuited secondary. These serve alternately to give the desired counter e.m.f. under overload or short-circuit conditions when the direct-current ampere-turns are overbalanced by the alternating-current ampere-turns. The auxiliary saturating equipment is obviously an added complication and expense but the arrangement effectively limits current on a short circuit to a definite relatively small value without excessive drop in the series coil under normal conditions. Furthermore, the current on short circuit is readily controlled by varying the current in the saturating circuit.* If the saturation circuit is opened, the load circuit is practically opened also through reduction of current to magnetizing current of the choking transformers.

H. R. Summerhayes (by letter): Referring to the arrangement No. 4 of placing a large amount of permanent reactance in the a-c. circuit of shunt-wound synchronous converters in order to obtain a considerable drop in continuous voltage at overloads, tests of this arrangement are described, and oscillograph records, Figs. 2 to 6, are submitted with the paper.

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*See similar diagram and oscillograms in A. I. E. E. TRANS., Vol. XXVIII, Part I, 1909, pp. 729-731.

To my mind these oscillograph records do not show that any appreciable reduction of continuous voltage was effected by the addition of the reactance in the a-c. circuit until such a long time had elapsed that the protection was ineffective. In oscillogram Fig. 3, when the load of about 11,000 amperes is applied, this load increases from zero to 10,000 amperes in a short time; practically instantaneous as compared to the scale of the oscillograph, and the continuous voltage drops from 280 to about 175 in the same short interval of time.

The oscillograph in Fig. 4, which was taken at the same time as Fig. 3, shows that when the load is applied, the voltage across the collector rings of the synchronous converter drops rather gradually; that is, several cycles are required for this voltage to drop from about 310 to 220. It is apparent that this drop in the impressed voltage across the a-c. collector rings is due to the phase displacement shown in the diagrams, Fig. 1; this phase displacement means that the armature of the synchronous converter actually drops back in space from the position of the revolving flux and this mechanical displacement requires several cycles. This slow reduction in the voltage across the a-c. collector rings, which is evidently reduced by the phase displacement caused by the increase of current through the reactance, does not correspond to the sudden drop in continuous voltage at the time of the application of the load, which is apparently due entirely to *IR* drop in the armature and external circuit.

During the period of several cycles in which the alternating voltage across the collector rings is being reduced from 300 to 200, the continuous current and voltage remain practically constant. In fact a slight increase is shown in the current.

It is evident that if the d-c. load thrown on had been of a value sufficiently great to flash over the converter, the converter would have flashed over irrespective of the reactance in the circuit, since the original value of the d-c. load lasting about a tenth of a second was not limited by the reactance. One effect of the reactance appears to have been to increase the phase displacement and, in connection with the inertia of the armature, to start hunting. It further appears that the instantaneous value of d-c. load lasted long enough to trip a circuit breaker. The reactance undoubtedly reduces the continuous current after a period of several seconds, as, from oscillograph Fig. 5, it appears that the final effect of the reactance at the end of the period of hunting was to reduce the continuous current from the initial value of 10,200 to the final value of about 9000, but the action is too slow to protect the converter from flashing over or to prevent the circuit breaker from operating.

Presented at the 300th meeting of the American Institute of Electrical Engineers, Philadelphia, Pa., October 12, 1914, under the auspices of the Committee on Use of Electricity in Marine Work.

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SUBMARINE SIGNALING

THE PROTECTION OF SHIPPING BY A WALL OF SOUND AND OTHER USES OF THE SUBMARINE TELEGRAPH OSCILLATOR

BY R. F. BLAKE

ABSTRACT OF PAPER

Submarine signaling has been greatly advanced by the introduction of a powerful sound transmitter and receiver called the "Fessenden telegraph oscillator." By means of this, telegraph messages can be sent and received through the water by moving ships and for short distances speech can be transmitted, icebergs can be located, and soundings taken instantaneously.

The apparatus consists of an oscillating electric motor-generator which has a strong electromagnet surrounding a central core on which is an alternating-current winding. Between the core and the magnet is a copper tube which acts as a closed secondary to the core winding. This copper tube is attached to a large diaphragm. When the alternating current passes through the core winding it induces a current in the copper tube, which, being free to move, vibrates back and forth, thus setting the diaphragm in vibration.

This apparatus is installed in a ship so that the face of the diaphragm is in contact with the water and its vibrations set up sound waves in the water. Signals have been sent a distance of 31 miles.

The oscillator can also be used as a receiver. Sound waves striking against the diaphragm cause the copper tube to vibrate, thereby generating a current in itself which is induced in the core winding. A telephone receiver in the armature circuit enables the observer to hear the sound.

COMPARED with other forms of transportation, the amount of energy necessary to transport water-borne freight is very small and its cost would be cheap indeed if it were not for the dangers of the sea. We have fogs and rocky coasts, shoals and icebergs, currents and storms to guard against, and these add immensely to the expense. Of this we have had a very recent instance, for, as the result of the loss of the *Titanic*, vessels carrying passengers are now constructed with a complete double bottom extending above the water line; in other words, instead of a single ship, we must now have two complete ships, one entirely enclosed by the other. And the loss of the *Empress of Ireland* indicates that even this may not be adequate.

Bit by bit the dangers which beset the early navigators have been overcome. The chart told him the best course to take from one point to another. The mariner's compass enabled him to maintain his course when the stars were blotted out by clouds. With sextant and chronometer he located his position, with log and soundings he guarded himself when a sight could not be obtained. More recently wireless telegraphy has enabled him to call assistance in time of danger. But with all this, many dangers remain. The more important of these are due to fog.

The North Sea, the English Channel and the Grand Banks, the New England coast, the western coast of the United States, British Columbia and Alaska, and other points are all of them subject to fogs, sometimes lasting for weeks at a time, and it is therefore not surprising that thousands of lives are each year still lost at sea.

And there is not only loss of life; the pecuniary loss is also very great. It is no unusual occurrence for a score of steamers to be tied up at one time, unable to enter harbor on account of fog or of the combination of fog and rough weather.

In such a case, the loss to the steamship companies in interest and depreciation on ships and cargoes and in wages may easily amount to more than fifty thousand dollars per day, and this loss occurs not once but frequently during a year, and on many routes.

In addition to this, the danger of collision in fog adds very considerably to the cost of insurance, and some of our worst disasters have occurred in this way.

Aside from those dangers peculiar to fog, there remains a number of others. A continuance of cloudy weather or abnormal ocean currents or both, may throw the navigator out of his reckoning and place him on a rocky shore a score of miles away from the safe route he assumes himself to be following.

Icebergs still remain a menace in spite of all the efforts which have been made to guard against them. From time to time, statements have been made that apparatus has been devised which is capable of locating their presence, but in every instance in which such apparatus has been tested it has proved a failure.

The history of systematic marine protection by means of lighthouses and beacons does not go back very far. It is true that there were a few lighthouses such as the Pharos of Alexandria

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centuries ago, but even in quite recent years a European Government received a petition for compensation from the inhabitants of a sea coast district on the ground that the erection of a lighthouse had deprived them of one of their principal sources of income, to wit, luring vessels on nearby shoals by means of false lights.

The systematic employment of sound signals for marine protection is of still more recent date and has never been carried out fully, in spite of the fact that many of our greatest scientists, for example Tyndall and Rayleigh, have devoted special attention to this matter.

One reason for this is that sound signals produced in air are very erratic in their range and intensity, so much so as to be on many occasions absolutely misleading. This is due to the fact that when a fog-horn is blown, the sound may be carried by the wind or may be reflected or refracted by layers of air of different densities, with the result that the sound may be audible many miles away while there may be a zone of complete silence extending from a few hundred yards in front of the signal to a distance of four or five miles.

As this phenomenon is by no means infrequent, the result has been to discredit more or less this type of signal, and it will be evident that the knowledge that a siren had been installed at a certain dangerous point might prove a source of danger instead of a protection.

As already stated, many eminent men have worked upon this problem, but it was not until Arthur J. Mundy, of Boston, suggested the use of water instead of air as the medium for transmitting signals and proved its value by practical demonstration that any great advance was made. Water has many advantages over air for this purpose.

1. In the first place, it is free from the dangerous zones of silence which occur when the signals are produced in air.
2. In the second place, the absorption of the sound is much less in water and consequently the signal is not only absolutely reliable but is transmitted to a distance many times greater than when it is transmitted through air.
3. The sound is not carried away by the wind in stormy weather, as is the case with the siren.
4. It is not affected by atmospheric disturbances, as in the case of wireless.
5. It permits of the accurate determination of the direction

from which the sound is proceeding, which is not the case with either the air siren or wireless telegraphy.

Some recent instances where ships have signaled by wireless that they were in distress but have had to remain without assistance for many hours, and in one instance for more than a day, because their location could not be determined by the vessels coming to their aid, will be familiar to every one.

All these advantages indicated clearly years ago the advisability of developing apparatus for signaling by means of sound waves transmitted through the water itself.

But it is one thing to conceive the idea, and another thing to develop a practical system, and it may be of interest to know that up to the present time the sum of a million dollars has been invested in developing submarine signaling, so far without monetary return.

The first method which was employed for producing the sound was through the striking of a bell and the method of receipt of the signals was by means of a microphone attached to the skin of the ship. Neither the original bell nor the original microphone attachment was satisfactory.

It would be impossible in the space permitted to discuss even briefly the innumerable experiments made with different sizes of bell, with different materials for the bell, with different methods of producing the blow, the precautions taken to eliminate electrolytic action, with different types of microphone, with different methods of mounting the microphone on the side of the ship, with the experiments made to minimize water and other noises. It will be sufficient to say that finally the work of Mundy, Wood, Fay, Williams and others resulted in a completely practical system.

The submarine bell in use on the lightships is actuated by compressed air stored in a reservoir. The actuating wheel has projections mounted on it so that when the wheel revolves a number of strokes follow each other, the different intervals being peculiar to the different signal stations so that the captain of a ship by counting the strokes of the bell can determine what lightship is producing the sound.

In order to receive the sound, it has been found absolutely necessary to suspend the microphone in a tank of water, for this is the only method of cutting out the water noises and the noises due to machinery, etc., on board the ship, which otherwise drown out the sound of the bell.

One of these small water tanks, containing a microphone of a special type, is attached to each side of the bow inside of the ship. From each tank wires are run to a device which is called the indicator box, so arranged that by throwing the handle to one side, the starboard microphone is connected to the telephone, and by throwing the handle to the other side, the port microphone is connected.

It will be obvious that once the bell is picked up, the captain has only to turn his vessel until the sound is heard with equal intensity on each side, to know that his ship is then pointing in the direction from which the sound is coming, and in this way he can take compass bearings of the lightship on which the bell is situated.

The importance of this method will be at once perceived. No matter how stormy or how foggy the weather may be, it enables the captain of a ship, on making land, to obtain at once the compass bearings of the nearest lightship or lighthouse fitted with a bell.

How many vessels and how many lives this device has saved even in the few years during which it has been in use, it would be impossible to tell. Less sensational than the wireless telegraph, it may be questioned whether its actual practical utility to the merchant marine has not been greater.

Compressed air, or an electromagnetic mechanism, may swing the hammer, or the bell may be operated by the waves themselves. A type much used is a bell buoy which may be anchored off a shoal, and will give submarine warning day and night without further attention. A large vane extends from one side of the mechanism. As the buoy swings up and down in the water, the vane by means of a ratchet compresses a spring which automatically releases and operates the bell hammer.

It will be evident that, even if no further development had been made, the system would be and is a complete and practical one. Its universal adoption would greatly minimize if not entirely prevent disasters due to errors of ship position.

But with the very success of this system, it became evident to those in charge of its development that still further advances might be conceived as possible, especially in three directions.

1. Suppose the sound-producing apparatus could be so constructed as to be operated from moving ships by a telegraph key. If this were achieved, it would be possible for one ship to signal to another in fog, to communicate its position, its

direction and its speed, and eliminate all dangers of collision. It would also be possible to signal between submarines or between battleships and submarines, and to communicate between battleships in action without interference from the enemy and though all masts were shot away.

2. Suppose the range of the sound-producing apparatus could be extended so as to cover a radius of 25 or 50 miles. Then it would be within our power so to encircle the coast of every nation, with what has been felicitously termed "a wall of sound," that no vessel under whatsoever circumstances of loss of reckoning, of variable currents, of fogs, and storms could approach the coast without being warned of that fact and notified of its exact position on that coast and of the direction of the nearest lightship.

3. If the sound-producing apparatus could be constructed so as to be actuated by telephonic currents, it would be possible to transmit speech through the water.

It will be of interest to consider some of the difficulties which had to be overcome before the desired results could be obtained.

The most serious of these obstacles was the fact that water is almost incompressible.

Now since sound is a compressional wave in the medium through which it is transmitted, it is evident that any apparatus which is to transmit sound through water must be capable of exerting very great force. In the bell, this is accomplished by the hammer blow of the clapper, and any electric or other apparatus which is to be used for submarine signaling must have a force comparable with that produced by the impact of a hammer on an anvil.

A second and very grave difficulty arises from the fact that if the water is to be compressed, some material object must be set in motion to compress it, and that object, which must have sufficient mechanical strength to stand the stress, and must therefore be of considerable size, must start from rest, reach its highest velocity, and come to rest in one-thousandth part of a second, if a musical note having a pitch of five hundred per second is to be produced. The forces of acceleration thus necessitated are very large.

A third difficulty arises from the fact that in order to telegraph a. a speed of twenty words per minute the time allowable for a single dot is very small. As the average word consists of five letters, and the average letter has a length equivalent to seven dots, an apparatus capable of telegraphing at the rate of twenty words per minute must be capable of making seven hundred dots per minute, or a single dot in something less than one-tenth of a second.

If the signal is to have individual quality, so as to be readily distinguishable from other noises, and so as to be separable by resonance from other notes, each dot must consist of at least ten impulses.

Thus we arrive at the conclusion that whatever device is used, it must be capable of producing at least 100 compressional waves in a single second, in order to telegraph satisfactorily at the rate of twenty words per minute.

If this same apparatus is to transmit speech through the water, it must be still more rapid in its action and must be capable of producing several thousand compressional waves per second.

The above were the three main difficulties in the way. Of course there were many others—for example, the apparatus must not weigh too much; it must not be affected by water or change of temperature; it must be simple in construction; it must be easily applied to the ship; positive in its action; must not require adjustment after being once set up and must be able to stand all kinds of ill-treatment at the hands of unskilled operators. It will be unnecessary to go over the ground taken by the development, and we will therefore proceed at once to describe the apparatus as finally developed by Professor R. A. Fessenden.

The device used is termed an oscillator and its construction is shown in cross-section in the drawing, Fig. 1.

In the drawing, the iron of the magnetic circuit and the copper tube are shaded. The magnetizing coil is cross-hatched. The moving part is the copper tube *A*. This lies in the air gap of a magnetic field formed by a ring magnet *B*, built up in two parts, as shown in longitudinal section in Fig. 2.

The ring magnet is energized by the coil *C*, and produces an intense magnetic flux which flows from one pole of the ring magnet across the air gap containing the upper part of the copper tube, thence through the central stationary armature *D*, thence across the other air gap to the lower pole face of the ring magnet and thence through the yoke of the ring magnet back to the upper pole face.

This field is very much stronger than that in the ordinary dynamo, there being more than 15,000 lines for each square centimeter of cross-section.

Around the armature is wound a fixed winding, which we will call the armature winding, and which is reversed in direction so that one half of the winding is clockwise and the other counter-clockwise.

When an alternating current is passed through this armature winding, it induces another alternating current in the copper tube.

Only by this construction has it been found possible to obtain the enormous force and rapidity necessary to compress the water and to overcome the inertia of the moving parts of the mechanism.

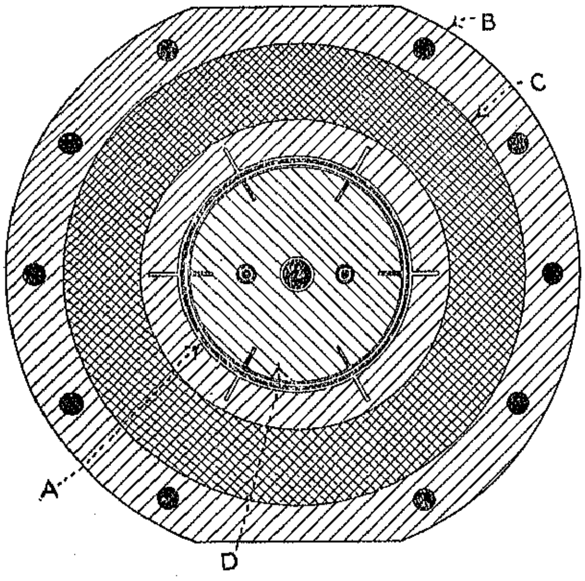

Fig. 1

In order to apply this force to the work of compression, the copper tube is attached to solid disks of steel, which in turn are attached to a steel diaphragm one inch thick which may be made part of the side of the ship. In practise the tube is provided with lugs, and is held between two disks drawn together on the tube by a one-inch vanadium-steel rod and a right- and left-handed screw thread.

Telegraphing is accomplished by means of an ordinary telegraph key placed in the main armature circuit.

Although an ordinary telegraph key is used, there is no sparking at the contacts. This may surprise electrical engineers familiar with the sluggish action and vicious arcing commonly found associated with the operation of electromagnetic apparatus of this size and power, more especially in view of the fact that a very high frequency is used, five hundred per second, and that there is no laminated iron used in the construction of the apparatus.

The secret of this lies in the fact that the armature has substantially no self-induction, and no eddy currents are generated in the apparatus. This is because the copper tube forms, as will be seen, the short-circuiting secondary of a transformer, of which the armature winding is the primary.

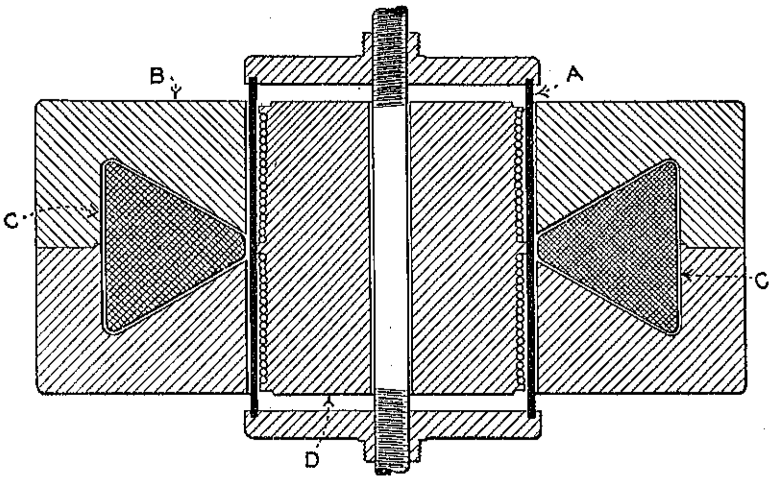

Fig. 2

This eliminates the self-induction of the armature winding. In addition the upper and lower portions of the winding are wound in opposite directions, and therefore there is no mutual induction between the field coil circuit and the armature circuit. With this construction, the amount of magnetic leakage in the armature circuit is very small, only a trifle more than if the armature core were of wood, and as there is no alternating magnetic flux in the iron, there are no eddy currents.

As regards the capacity in kilowatts of this apparatus, it is large. The armature, being wound in grooves in the armature core, so as to withstand the mechanical forces acting upon it, is well cooled.

The copper tube has no insulation to be affected, and on account of its large cooling surface and high permissible temperature of operation, can carry very high currents without injury.

When the oscillator is placed on a vessel or hung overboard from a lightship, a large water-tight diaphragm is attached to the oscillator. This particular type of oscillator was first tested by suspending it in twelve feet of water at the Boston lightship and the signals were heard plainly with a microphone lowered overboard from a tug at Peaked Hill Bar Buoy, thirty-one miles away. Since that time tests have been made with oscillators installed in the fore peak tank of the *Devereux*, a collier of the Metropolitan Coal Company, and also with an oscillator mounted on a diaphragm made part of the hull of the vessel. The signals have been heard upwards of twenty miles from the *Devereux* running at her regular speed of eight knots. Full power has not been employed on any of the tests, and it is more than probable that much longer distances can be obtained in the future.

In addition to the tests already described the oscillator has been temporarily installed on submarine boats, and proved itself of immense value and demonstrated that a flotilla of submarines equipped with oscillators will be able to make a combined attack on an enemy, only one needing to show its periscope in order to direct the others, or all of them can be directed by the mother ship. It therefore makes possible a whole field of submarine maneuvers heretofore out of the question; and perhaps most important, it removes the principal danger these boats have had to face, the risk of being run into.

So much for the apparatus when in use as a sound generator. The signals produced by the oscillator can of course be received by water-immersed microphones of the usual type, but one would perhaps not anticipate the possibility of using the oscillator as a receiver, in view of the fact that the diaphragm is of solid steel, and weighs, with the copper tube and its attachments, considerably over 100 pounds; but the oscillator, like the ordinary electric motor, is also capable of acting as a generator, and on account of its high efficiency as a motor, is a very efficient one.

The same oscillator is therefore used for sending and for receiving, a switch being thrown in one direction when it is desired to telegraph under water, and thrown the other way when it is desired to listen in.

In addition to telegraphing and receiving messages, the oscillator can also be used for telephoning under water. Sentences have been transmitted at 800 yards and conversation at more than 400 yards, and this was accomplished with the use of an ordinary telephone transmitter and 6 dry cells.

It seems evident, therefore, that with more power much greater distances can be reached. Long distances are not, however, necessary, as even with a distance of one mile it will be readily understood that this method of under-water telephoning will be of great use as a means of communicating between submarines while submerged, and between ships in fog, as the captains of the vessels can talk directly to each other, instead of transmitting and receiving through a telegraph operator.

Some other uses to which the oscillator may be put may be mentioned briefly.

One which will at once suggest itself is the steering of torpedoes by sound under water. The idea of so operating torpedoes is not a new one, and has occurred to a number of inventors, but until the present time no method of accomplishing it has been developed. With this new source of sound, however, the method should be practicable.

Another use is as a means for obtaining soundings. If we take a commutator wheel, with one live segment and two brushes, one connected to the alternating-current generator and the other to the telephone receiver, it will be evident that when the commutator segment makes contact with the brush connected to the generator, a sound will be produced by the oscillator. When the live contact passes away from the brush, the sound will cease. This sound wave will travel outward and on reaching the bottom will be reflected and travel back again to the ship. Meantime, no sound will be heard in the telephone receiver, but if the brush connected to the telephone receiver be shifted in the direction of rotation of the commutator until it makes contact with the live segment of the commutator, at precisely the instant at which the reflected sound wave has come back and impinged on the oscillator diaphragm then a sound will be heard. Since sound travels in water at a velocity of approximately 4000 feet per second, if the distance be 100 feet, the time taken by the sound in traveling from ship to bottom and from bottom to ship will be approximately one-twentieth of a second.

In April, 1914, some tests were made on the U. S. revenue cutter *Miami* to see whether soundings could be taken in the manner above indicated. As the commutator had not been completed a temporary apparatus with a stop watch was used. The echo from the bottom was plainly heard not only on the oscillator, but in the wardroom and in the hold of the ship without any instruments whatever. The elapsed time corresponded to the depth shown on the chart and the proposed method was proved to be feasible.

The chief object of the tests on the *Miami* was, however, to determine whether a reflection from icebergs could be obtained, and this was proved beyond question. The apparatus used was the same as for taking soundings.

A signal was sent on the oscillator, the echo from the bottom heard, and then the echo from the iceberg came in. To make sure that the second echo was not also from the bottom, the distance from the *Miami* to the iceberg was varied from about 100 yards to 2½ miles. The elapsed time between the signal and the echo from bottom remained the same, but the elapsed time of echo from the iceberg varied with the distance and corresponded very closely to the position of the iceberg determined by the range finder. Moreover it was found that it made no difference whether the face of the iceberg was normal to the path of the sound or not, thus showing that the echo was due not to specular reflection but to diffraction fringes.

When the *Miami* had gone 2½ miles from the iceberg a heavy storm made it necessary to postpone further tests, and continued rough weather made further tests impossible, as the oscillator was not permanently installed but had to be lowered overboard. The echoes at 2½ miles were, however, loud, and there can be no doubt that they would have been heard at greater distances. (See appendix).

To sum up: The oscillator represents an important step forward in the science of navigation. It makes it possible to surround the coasts with a wall of sound so that no ship can get into dangerous waters without warning, to make collisions between ships possible only through negligence. Although no sufficient tests have been made to warrant the statement that icebergs can be detected under all circumstances or that soundings can be taken at full speed, what evidence there is points that way. For naval purposes it provides an auxiliary means of short-distance signaling that is available at all times and that cannot be shot away, and it widens the possibilities of submarine boats to an extent we cannot yet fully grasp.

REPORT OF CAPTAIN J. H. QUINAN OF THE U. S. R. C. *Miami* ON THE ECHO FRINGE METHOD OF DETECTING ICEBERGS AND TAKING CONTINUOUS SOUNDINGS.*

We stopped near the largest berg and by range finder and sextant computed it to be 450 feet long and 130 feet high. Although we had gotten within 150 yards of the perpendicular face of this berg and obtained no echo from the steam whistle, Professor Fessenden and Mr. Blake, representatives of the Submarine Signal Company, obtained satisfactory results with the submarine electric oscillator placed 10 feet below surface, getting distinct echoes from the berg at various distances, from one-half mile to two and one-half miles. These echoes were not only heard through the receivers of the oscillator in the wireless room, but were plainly heard by the officers in the wardroom and engine room storeroom below the water line. Sound is said to travel at the rate of 4400 feet per second under water. The distance of the ship, as shown by the echoes with stop watch, corresponded with the distance of the ship as determined by range finder. On account of the great velocity of sound through water, it was our intention to try the oscillator at a greater distance for even better results, but a thick snowstorm drove us into shelter on the Banks again.

* * * *

On the morning of April 27, anchored in 31 fathoms of water with 75 fathoms of chain in order to make current observations. . . .Professor Fessenden also took advantage of the smooth sea to further experiment with his oscillator in determining by echo the depth of water; the result giving 36 fathoms, which seemed to me very close.

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*From the *Hydrographic Office Bulletin* of May 13, 1914.

DISCUSSION ON "SUBMARINE SIGNALING" (BLAKE), PHILADELPHIA, PA., OCTOBER 12, 1914.

W. S. Franklin: When you lower that oscillator into the water, the two diaphragms are working in like phases, are they not?

H. J. W. Fay: Yes. That means that the water on one side is being compressed.

W. S. Franklin: Don't you cover one of those diaphragms completely, and only expose one to the water?

H. J. W. Fay: This diagram doesn't show the water-tight oscillator as it should. This is a form of oscillator that was put inside the ship, not put in the water. A water-tight oscillator has a ring around the base of the pole piece, and the third diaphragm is mounted on that ring, and this rod excites that diaphragm.

W. S. Franklin: If I may explain just what I have in mind—you say that your wave length there would be something like thirty or forty feet. Now we speak of each side of that apparatus as being a center from which waves go out—

H. J. W. Fay: No, only one side.

W. S. Franklin: That is what I wanted to know. Only one side is covered?

H. J. W. Fay: Yes.

Elmer A. Sperry: This seems to me a most ingenious apparatus. Think of the diaphragm that you and I use when we speak into a telephone, a small affair that is about as thick as paper, and then consider the diaphragm that this apparatus works—three-quarters of an inch thick and 24 inches in diameter; and it takes that size of diaphragm to be in tune with the 1000 beats or 500 full oscillations per second to which this instrument is tuned with the alternating current of this frequency. I understand that when this was tried on the *Delaware* it was heard distinctly on the upper deck in a very remote position from where the apparatus was installed. But the most remarkable thing to me is that it can be again used as a receiver. The 8 by 8-in. copper tube, only $\frac{1}{8}$ in. thick, seems a very simple factor to set up a reaction back into the alternating winding, giving evidence of remote sound, especially when in attune with this diaphragm.

G. A. Hoadley: The paper speaks of the most important use of this apparatus on submarines, for submarine signaling from one vessel to another. Has there been any method devised by means of which submarines not belonging to our party can be prevented from receiving the message?

H. J. W. Fay: No, not yet. At a mile's distance, the sound is so loud that it can be heard all over the submarine boat without any receiving apparatus. The point that you mention has been in mind, but it could not be done with vibrations such as are used now. It would be possible with vibrations that are below the range of audibility.

H. A. Hornor: Have any experiments been made upon interference of two signals at a time? Wouldn't that be a cause of confusion of the signals?

H. J. W. Fay: Yes, probably, unless they were widely different in tune. Then the oscillator at 500 might not pick up the oscillator that was tuned to 1000. We have simply worked the oscillator out for that one pitch at the present time, and the greatest number that we have known to be used at any one time has been two. We have not had a third oscillator in any of the tests to break in on the signals.

W. S. Franklin: Professor Webster of Clark University has been working quantitatively on a problem which involves making, among other things, an accurate measurement of the number of watts that are given out as sound by ordinary tuning forks, with and without resonance. Have you any idea as to the actual watts output represented by the sound that is produced? I don't mean watts entering into the receiver, but watts of energy in the sound.

H. J. W. Fay: The nearest I can tell you is that last Saturday we made a test with one oscillator 46 ft. from the other and measured the amount of current received in the alternating winding of the receiving oscillator, and we got 0.025 ampere. The input was 13 amperes at 170 volts on the alternating current and 7½ amperes at 110 volts on the direct-current winding.

George Breed: As I understand the description, the armature oscillates in a direction longitudinal with the bolt. Then, presumably, it must be centered in some way and held clear and free between the magnet poles, and furthermore, if it be free to oscillate, its supports cannot be absolutely rigid.

It would be interesting to know how the armature is held in place, and how much elasticity there is in its supports. I suppose the oscillating system thus formed is so proportioned with respect to mass and elasticity, that its natural frequency of oscillation is about 500 per second.

H. J. W. Fay: The amplitude of movement is 0.01 in. The small diaphragms on the rod support the copper tube.

W. S. Franklin: If the amplitude of this apparatus is known, Professor Webster's formula will enable the actual watts of sound output to be calculated with a very high degree of accuracy.

John B. Taylor (by letter): Before commenting in detail on the paper by Mr. Blake, a few very general (and perhaps obvious) remarks may be in order.

Communications between individuals more or less widely separated may be accomplished only by transfer of matter or energy from one to the other. Exchange of intelligence by moving material things has culminated in the typewritten letter.

The spoken word and the sign exemplify communication through forms of energy. Here one involves mechanical, the other radiant energy. In the business of travel and transportation by land, as well as by sea, both audible and visible signals are extensively employed, one supplementing the other. Light signals serve fairly well in disclosing location or direction through "straight-line" propagation of the radiant energy and the working characteristics of the receiving instrument, the eye. Non-transparent objects cast shadows, *i.e.*, the radiation does not bend around obstacles, hence rain, snow and especially fog disturb, or prevent entirely, dependence on visual signals. Layers of air of different optical properties may also give rise to mirages or other aberrations.

Sound signals do not readily disclose location or direction. Sharp sound shadows are not noticed with wave lengths of the pitches commonly employed, and the ears are not well adapted nor trained to locate sources of sound with assurance or accuracy. Further difficulties arise on account of reflections from objects giving echoes or interferences which may be misleading, while other sounds and noises, necessary and unnecessary, reduce the sensibility of the ear to feeble sound and distract the attention from the particular sound signal.

The paper under discussion describes a system of marine sound signaling using the water of ocean, river or lake rather than the air as transmitting medium. To do this, more complicated sounding and receiving equipment is needed. Doubtless the water will usually be more homogeneous acoustically than the air. The inhabitants of the water are assumed to be comparatively quiet. There are, however, extraneous sounds which give trouble. Is it right to infer that these are greater than undesired sounds in the air, since no mention of this point is made in the list of five advantages of water over air? (page 1551).

The descriptions of the determination of depth and of iceberg distance by echo and reflection naturally lead one to question the reliability of direction location in the presence of other ships, icebergs, rock ledges, reefs, islands, not to mention shore and bottom.

The greater speed of transmission through water (approximately 4 times) is an advantage from a telegraphic standpoint where sound signaling through air would leave the hearer a full minute behind the sender in 11 or 12 miles. In fact, the 15-sec. interval for water signaling for the same distance may make much confusion. The greater velocity is a disadvantage in depth and distance determinations.

The remarks of the author (page 1554) on compressibility of water and large forces and strength of materials needed to make a sound in water are incomplete without data on the number of kilowatts expended and the excursion of the copper tube with its attachments and diaphragm. A steel rod will readily transmit the sound of a pin scratching or a watch ticking, though the velocity of sound in steel is about 14 times that in air and though steel is much heavier than water, thus indicating far greater rigidity or incompressibility than water.

What is the basis of the author's statement that a telegraphic "dot" must persist ten cycles for its pitch to be recognized? Lord Rayleigh ("Theory of Sound," Vol. II, page 452) cites tests to show that *three* consecutive vibrations determine pitch with considerable accuracy. Tests of Mr. Arthur Farwell (Massachusetts Institute of Technology thesis, 1893, I believe unpublished) using a different method—a telephone receiver—corroborate the figure.

Submarine signaling by the "telegraphic oscillator" may well supplement other signal methods, as none are complete and at all times dependable. Sound signals through air must be retained for the benefit of small craft that cannot have submarine devices. Though a given sound may not always be heard at the same distance, the air is the natural medium for men. The ear, while sensitive to feeble sounds, may be aided, and an increased range may be obtained by the help of apparatus. Probably many cases of alleged erratic transmission of sound are due to mistakes in judging direction. To determine better the direction of the source of sound, an interference device or apparatus indicating phase of sound at two slightly separated points determines the direction from which the sound wave arrives (see U. S. patent No. 939,349).

G. A. Hoadley: One question in connection with this paper is the necessity of a high degree of energy in sending out the sound. A pin scratch on a wire fence can be heard at a long distance, not because the steel or iron wire used is so little compressible, but because of its high elasticity, and it seems to me that in the case of submarine signaling it is a question of higher elasticity of the medium rather than the amount of the compression that is to be used. I am questioning whether it would be possible in any way to apply less energy and still set up the wave motion.

J. L. Woodbridge: How accurately can the direction from which the sound proceeds be determined by the receiving vessel?

H. J. W. Fay: Within a point on the compass, or 11¼ deg., at distances of between two and three miles.

W. S. Franklin: The accuracy of locating directions of sound must depend on the distance apart of the two points at which the sound is received. How far apart are the two receivers when you attempt to locate directions of sound—ten feet, or so?

H. J. W. Fay: The distance between the two sides of the bow of a ship—more than ten feet.

Presented at the 300th Meeting of the American Institute of Electrical Engineers, Philadelphia, Pa., October 12, 1914, under the auspices of the Committee on Use of Electricity in Marine Work.

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ELECTRICAL EQUIPMENT OF THE ARGENTINE BATTLESHIP "MORENO"

BY H. A. HORNOR

Abstract of Paper

This paper describes the electrical installation of one of the two Argentine battleships building in this country and now nearing completion. The methods of installation and distribution of energy; the extensive application, far surpassing any vessel so far constructed in this country, and the results secured by departure from present practise; all these are concisely recorded. Detailed descriptions are given of important and unusual equipments such as steering gear, anchor windlass, searchlights, gyro-compass, etc., etc.

THE MORENO is one of the two super-dreadnoughts building in this country for the Argentine Republic. The general characteristics of the *Moreno* are as follows:

Length over all, 594 ft. (181 meters); displacement, 27,566 tons (28,000 metric tons); draft, 27 ft. 9 in. (8.46 meters); width 98 ft. 0 in. (29.89 meters); main battery, twelve 12-in. (304.8-mm.) breech-loading rifles mounted in six turrets; torpedo defense battery, sixteen 4-in. (101.6-mm.) and twelve 6-in. (152.4-mm.) breech-loading rifles.

It is the purpose of this paper to describe in general the electrical equipment of this vessel. The applications are so numerous and varied that only the unusual equipments have been selected for detailed comment. By reason of the confidential nature necessarily involved in military applications, all reference to such has been omitted. As all installations of this character are divided into three general systems, namely, lighting, power, and signaling, this grouping will be followed.

Generating Plant

Power for all purposes is supplied by four 375-kw. turbo-generators of the horizontal type. Two of these machines are located forward and two aft on the lower platform deck below armor. Adjacent to each dynamo room is a distribution room in which is located a main distribution switchboard for the control of the two units and the supply circuits. On the gun deck is a third dynamo room containing two Diesel oil-engine-driven generators of 75 kw. capacity for harbor use when fires are drawn.

The 375-kw., 230-volt, 1500-rev. per min. turbo-generators are of standard marine design capable of operating at a steam pressure of 220 lb. per sq. in. (15.4 kg. per sq. cm.), condensing at a normal vacuum of 28 in. (71.1 cm.), and also non-condensing with 5 lb. (2.27 kg.) back pressure. The turbine is of the well-known Curtis horizontal, two-stage type, fitted with automatic valve gear, inertia governor, and an emergency valve for automatically closing when the speed exceeds 10 per cent of normal. Forced lubrication is provided for the main bearings, and the oil is cooled by water circulation. The generator is a compound-wound, direct-current, commutating-pole type, mounted on the same bedplate and directly coupled to the turbine. The magnet frame is circular in form and divided horizontally. The generator is capable of standing a 33⅓ per cent overload for two hours and 50 per cent overload for five minutes.

The Diesel oil-engine-driven sets are rated at 75 kw., 375 rev. per min., 230 volts. The generator is directly connected to the oil engine but not mounted on the same bedplate. The generators are designed in a similar manner and are capable of functioning in the same way as the main generators above described. The Diesel oil engine is guaranteed to develop 120 b.h.p. normally and also 180 b.h.p. overload. The engine is vertical, four-cycle, single-acting, and is provided with four power cylinders and one air-compressor. The engine is started by means of compressed air at about 650 lb. per sq. in. (45.5 kg. per sq. cm.) obtained from storage tanks. During the starting of the engine the cooling water is gradually started and will be in full flow when normal ignition has been established. The plunger for the fuel oil pump is operated by an eccentric attached to the vertical shaft of the valve gear drive. An auxiliary cooling water pump and fuel oil pump are also provided. These auxiliaries are electrically driven, the former by a 2.7-h.p. motor and the latter by a 1.75-h.p. motor. The fuel oil used may be fairly heavy, even heavier than 20 deg. Beaumé at 60 degrees fahr., so long as it flows readily and can be handled by the fuel oil pump. The heat value of the oil should not be less than 18,500 B.t.u. per pound (4662 kg-cal.).

INSTALLATION AND DISTRIBUTION

Current is carried to all the various systems on a two-wire metallic system, by means of rubber-covered (44 per cent pure Para) lead-sheathed, steel-armored conductors. These cables are clipped singly, or in groups, to the ship's structure or clipped to special sheet steel pans supported from beam to beam or fastened to the plating. Water-tight fittings are provided wherever the cables terminate and when passing through water-tight bulkheads. Twin conductors are employed from 3256 cir. mils up to 30,856 cir. mils, and beyond this, single conductors up to 373,737 cir. mils. All the conductors in this installation are stranded, lead-covered, steel-armored, with the exception of the flexible leads in the turret trunks and special brass-covered wire and three-conductor rubber-insulated wires, called by the German trade name "Kuhlo," used for branch leads in the officers' quarters and staterooms.

Besides the two main distribution switchboards located adjacent to the two dynamo rooms, there are two auxiliary distribution boards located one forward and one aft; a control board for the oil engine generators; and a combined distribution and control board for the searchlight balancer sets. These boards are all interconnected so that the supply will always be available. The interconnecting circuit breakers are fitted with interlocking devices and reverse-power relays so that by no possibility will the generators in one room be thrown in parallel with those in another room. The distribution switchboards are designed with separate busbars for positive lighting and positive power and a common negative. It is possible, therefore, to divide the load in various ways between the different dynamo rooms. To facilitate this, indicating voltmeters and ammeters are connected in the local and remote circuits and a diagram of the busbar connections is painted in grooves on the front face of the oil-finished slate panels.

LIGHTING SYSTEM

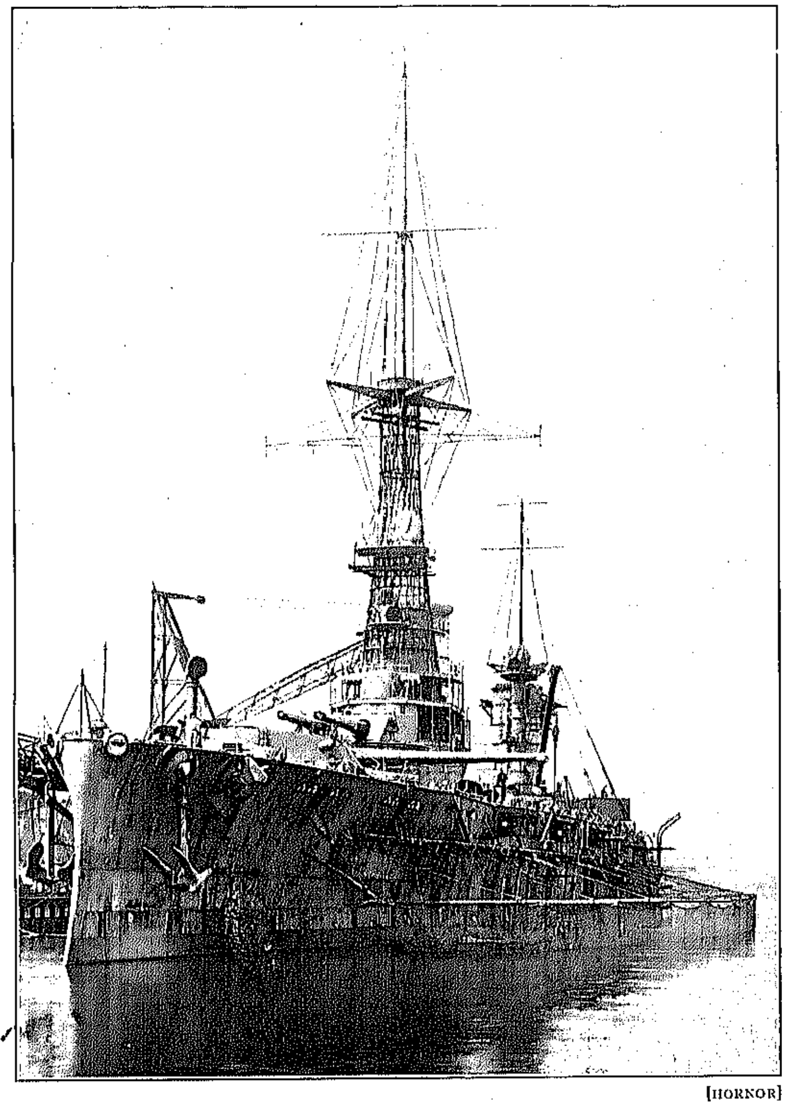
The vessel is provided with approximately 3000 fixtures. The design is similar to the usual water-tight vapor-proof globe type used in marine work. The screw-base lamp socket is, however, made solid instead of a spring, a composition-insulated base provided instead of porcelain and the globe is flanged and held in place by the guard instead of being screwed into the base. In the magazines and shell rooms, specially guarded fixtures containing two lamp sockets are installed. The lamps in these fixtures are connected to different circuits so that the failure of light in these compartments may be averted. Both carbon and tungsten incandescent lamps are furnished; the former in sizes of 35 watts and 60 watts, clear; the latter in sizes of 32 watts, clear, frosted and tubular. A special fixture containing a 250-watt tungsten lamp and provided with a reflector is arranged for portable connection in the engine, boiler, and dynamo compartments. This same type of fixture is also employed for coaling booms, propeller booms, and gangway lighting.

Life tests of the 220-volt tungsten incandescent lamps showed as high as 98 to 101 per cent of the initial c.p. after 1162 to 972 hours burning. The spherical reduction factor for the tubular lamp was 0.96 and for the pear-shaped bulb (s-19) was 0.914.

The 38 lighting feeders are divided into three circuits; one for general illumination under cruising conditions, one for white battle purposes, and one for blue battle purposes. In this latter circuit the globes are of a deep blue color, making the light invisible at a short distance. The distribution of the small lighting units has been made with due regard for cross circuits so that no general spaces of the vessel may be put in darkness by the blowing of a fuse or any other failure of an individual circuit. The distribution of these lights was based on the number of candle power per cubic foot of space to be lighted; thus in the Admiral's quarters a maximum of 0.08 c.p. per cubic foot was required and in the storerooms a minimum of 0.01 c.p. per cubic foot. Each officer's stateroom of ordinary size is provided with one fixed light, one portable light, and an outlet for a 12-inch portable electric fan.

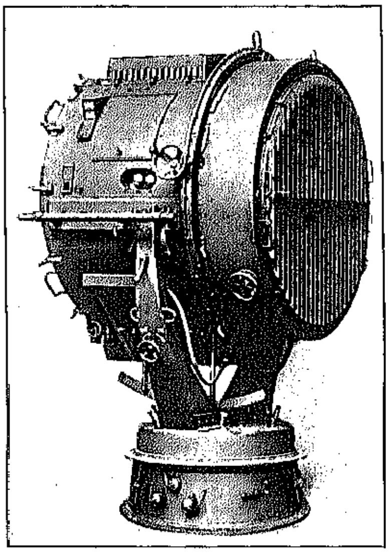
As shown in the diagram (Fig. 2) the feeders are led from the main distribution switchboard to approximately their center of distribution. Mains are then branched from the feeder, and terminate in fused distributing panels of water-tight construction. From these panels branches are led off to the individual lights. Not more than four lights (one ampere) are allowed to depend upon the same fuse. The branch leads are all of 1.6-mm. (3250-cir. mil) twin conductor.

For night battle purposes the vessel is equipped with 12 motor-operated, remote-electrically-controlled 110-cm. (43.3-in.) searchlights and one portable signaling projector of 35 cm. (13.77 in.). As these projectors operate more satisfactorily when supplied with 110 volts, it was considered advisable to



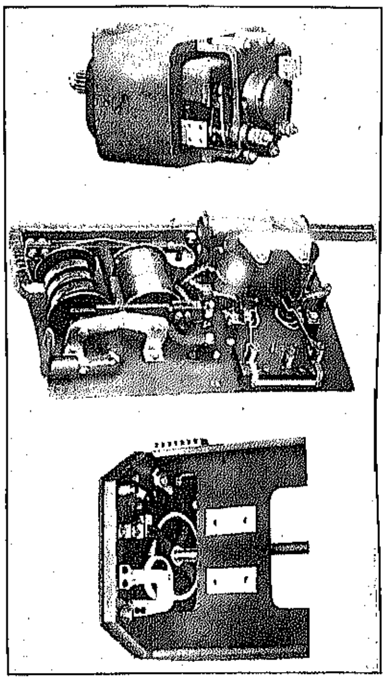
[HORNOR]

FIG. 1—*Moreno* AT THE YARDS OF HER BUILDERS, AUGUST 19, 1914



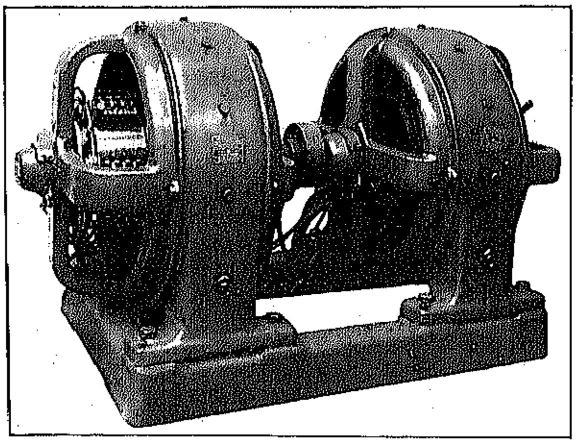
[HORNOR]

FIG. 3—ELECTRICALLY CONTROLLED SEARCHLIGHT



[HORNOR]

FIG. 4—SEARCHLIGHT LAMP MECHANISM



[HORNOR]

FIG. 8—SEARCHLIGHT BALANCER SET

transform the 220-volt supply circuit through special balancer sets. Two such machines are installed in the vicinity of the oil engine dynamo room, wherein are located the control switchboard for them and the distribution board for the search-light feeders. Each balancer set is rated at 70 kw., 1000 rev. per min., 110 to 220 volts, the full load current on the neutral being 637 amperes. They are compound-wound, and the series and shunt coils are connected so that they act accumulatively on the generator and differentially on the motor. The series and shunt coils in one frame are connected across the armature of the other frame for the purpose of producing constant voltage at each end. The sets will maintain a difference of potential not in excess of seven volts under any conditions of load with an impressed e.m.f. of 220 volts. Either end of these sets operates as a motor or generator as may be demanded by the load.

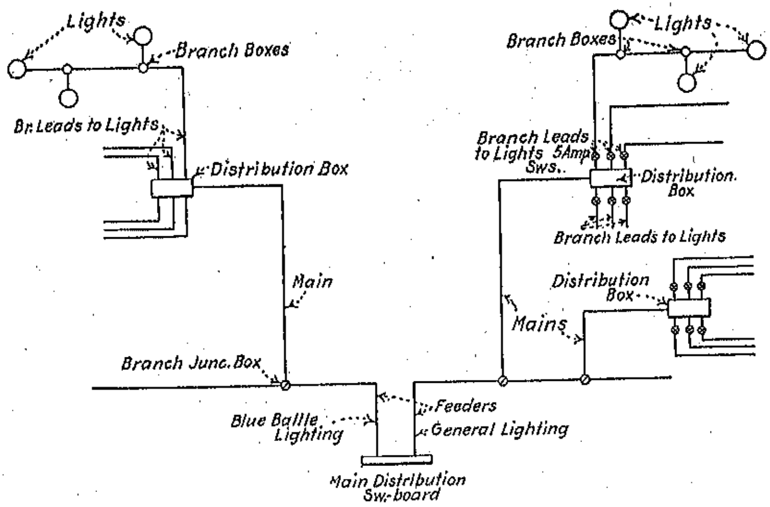


FIG. 2—DISTRIBUTION DIAGRAM

Only a brief description can be given of the searchlights proper. Fig. 4 shows the lamp mechanism. Fig. 5 is a wiring diagram when the carbons are apart, Fig. 6 the same with the carbons together, and Fig. 7 gives curves illustrating the time saved by the employment of a shunt motor for automatically adjusting the carbons in preference to a compound-wound motor. The twelve 110-cm. (43.3-in.) searchlights are similar in every respect except that one projector is equipped with a remote-electrically-controlled signaling shutter. The lamp mechanism consists of a small electric motor which functions through gearing and so moves the carbons. The field and armature of the motor are controlled by a differential relay and two auxiliary relays which cause the armature either to stop or rotate to right or left. The first takes place with the current and voltage normal, the second when the amperage is too high and the voltage too low, and the third when the last condition is reversed. Besides the regular field winding there is an additional winding on the motor field to carry the full lamp current. This produces a strong field when the voltage across the arc falls below normal and furnishes a dynamic braking effect for retarding the movement of the motor armature. For signaling purposes the searchlights are equipped

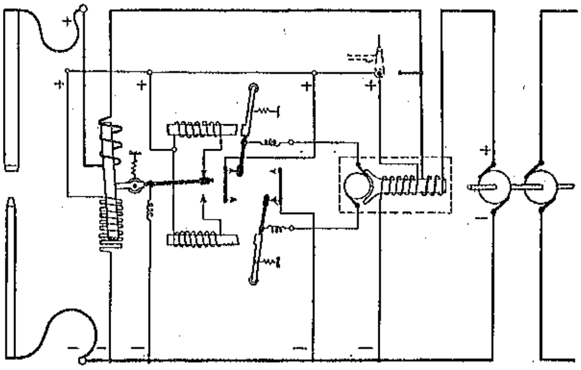


Fig. 5—Diagram of Lamp Connections—Carbons Apart

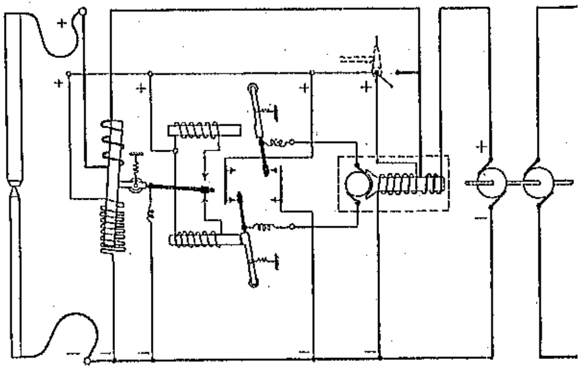
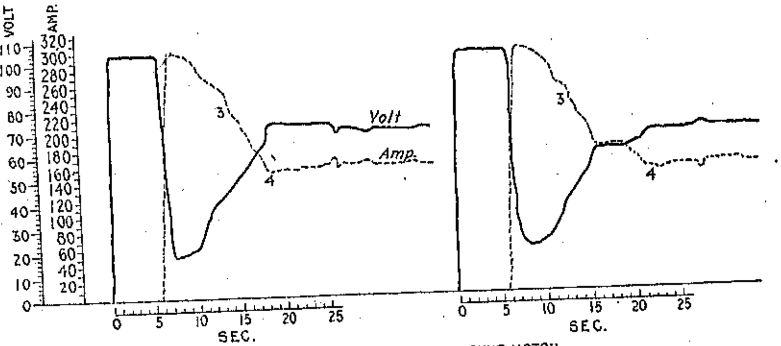
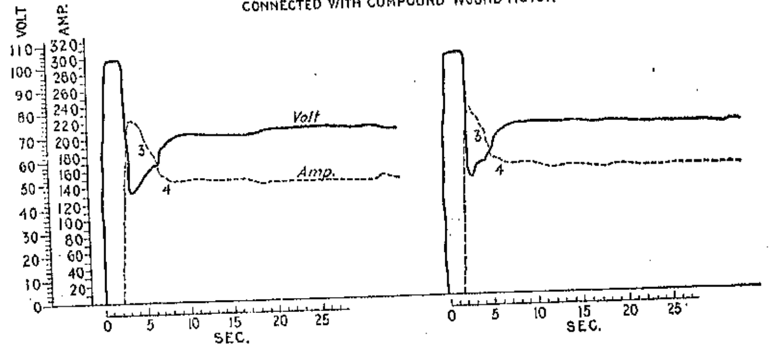


Fig. 6—Diagram of Lamp Connections—Carbons Touching

with iris shutters similar to camera shutters. These are all manually operated, except one, in which latter case a venetian blind shutter, remotely controlled, is also provided. The optical arrangements are such as to provide rapid means for changing over from a dispersed to a closed beam of light. This is accomplished by means of a double disperser, consisting of two parallel systems of plano-convex cylindrical lenses, which may at will be drawn together or separated. A sighting telescope attached to the side of the drum; a complete lamp telegraph indicating the positions of the searchlight at the controller; and a set of electrical instruments, consisting of a voltmeter and ammeter, are furnished with each searchlight. A complete horizontal cycle of the searchlight may be accomplished either in 28 seconds or approximately 15 minutes by means of the electric remote control. This control may be detached and the mechanism operated locally by hand.



CONNECTED WITH COMPOUND WOUND MOTOR



CONNECTED WITH SHUNT WOUND MOTOR

FIG. 7—TIME DIAGRAMS OF SEARCHLIGHT LAMP MOTORS

POWER SYSTEM

The following list shows the extensive applications of the electric power and gives the rated load for each equipment. It should be borne in mind that these numerous equipments have their special uses and are brought into action in general upon different occasions. Such systems as the ventilation system, sanitary pumps, etc., etc., are continuously in service; but on the other hand the deck machinery such as boat booms, deck winches, coaling winches, etc., is only used when in port coaling, handling small boats, etc. In like manner the turret machinery is only used under battle conditions or for practise drills.

No.	Equipment	Rated horse power	Total horse power
2	Boat Boom Hoisting	50.	100.
2	Boat Boom Topping	30.	60.
4	Deck Winches	35.	140.
16	Ammunition Hoists	3.	48.
6	Ammunition Hoists	5.	30.
12	Forced Draft Blowers	35.	420.
1	Anchor Windlass	100.	100.
1	Capstan	100.	100.
2	Coaling Winches	150.	300.
1	Steering Gear	150.	150.
3	Bilge Pumps	70.	210.
14	Bilge Pumps	35.	490.
2	Searchlight Balancer Sets	93.	186.
1	Fire Pump	60.	60.
2	Fresh Water Pumps	6.	12.
2	Sanitary Pumps	35.	70.
1	Drainage Pump	3.	3.
2	Thermo Tank Pumps	35.	70.
3	Turbine Lifting Gear	30.	90.
1	Laundry	6.	6.
1	Printing Press	0.25	0.25
3	Speed Signal Balls	0.5	1.5
1	Cake Mixer	1.	1.
1	Dough Mixer	2.5	2.5
1	Diesel Engine Oil Pump	1.75	1.75
1	Diesel Engine Cooling Water Pump	2.7	2.7
12	Turret Turning	25.	300.
12	Gun Elevating	15.	180.
13	Turret Hoists	7.5	97.5
5	Turret Hoists	12.	60.
1	Dryer Room	1.	1.
1	Roentgen Ray Equipment	5.	5.
1	Vacuum Cleaner	0.33	0.33
1	Electro - Mechanical Hammer	5.	5.
2	Torpedo Air Compressors	90.	180.
5	Refrigerator Pumps	19.5	97.5
5	Brine Pumps	3.5	17.5
2	Ozonizer Motor-Generators	1.3	2.6
2	Ozonizer Pumps	0.5	1.
9	Elevators	4.	36.
1	Wireless Motor-Generator	18.	18.
2	Alternating-Current Motor-Generators	37.	74.
1	Dish Washer	1.	1.
1	Meat Slicer	0.5	0.5
1	Meat Chopper	1.	1.
1	Potato Peeler	1.	1.
1	Ice Cream Freezer	1.	1.
1	Egg Beater	2.	2.
1	Extension Lathe	3.	3.
1	Tool Room Lathe, 14-inch	0.75	0.75
1	24-inch Shaper	3.	3.
1	30-inch Radial Drill	2.5	2.5
1	16-inch Sensitive Drill	0.75	0.75
1	14-inch Tool Room Lathe	0.75	0.75
1	Grindstone	1	1
1	46-inch Boring Mill	3	3
1	Cutter and Grinder	1	1
1	Tool Room Lathe 14-inch	0.75	0.75
1	Sensitive Drill 16-inch	0.75	0.75
1	Lathe for Armorer's Workshop	0.75	0.75
1	Shaper for Armorer's Workshop	2.	2.
1	Sensitive Drill for Armorer's Workshop	0.75	0.75
1	Forge Blower	0.75	0.75
1	Foundry Blower	5.	5.
1	Athletic Horse	2.	2.
1	Moving Picture Machine	17.6	17.6

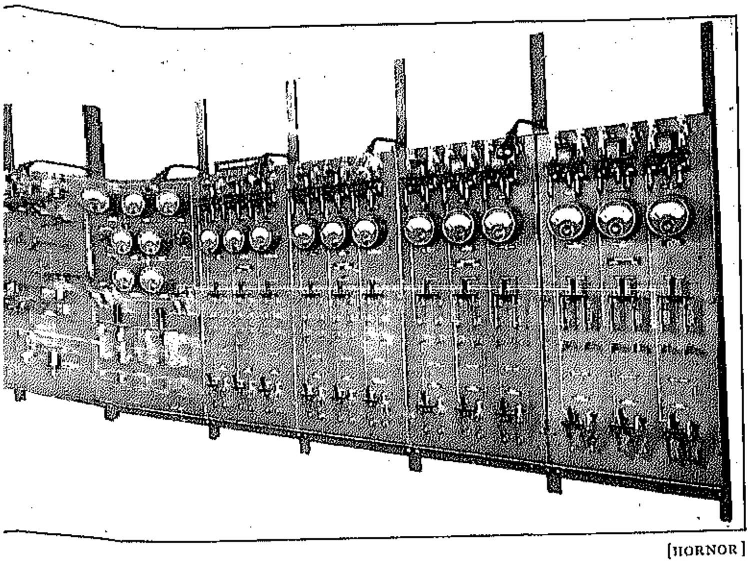

[HORNOR]

FIG. 9—SEARCHLIGHT DISTRIBUTION SWITCHBOARD

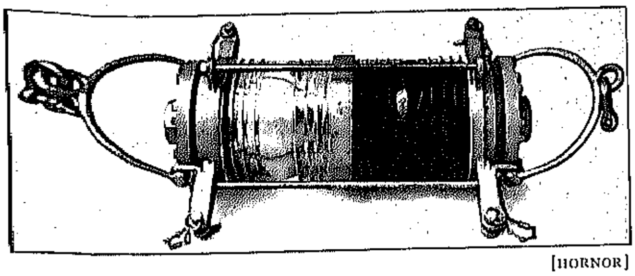
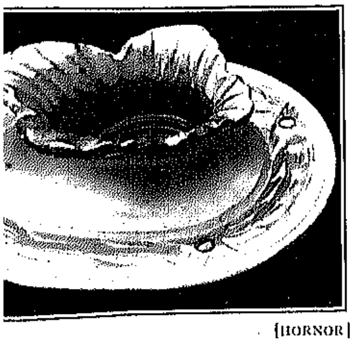

[HORNOR]

FIG. 9a—NIGHT SIGNAL SET LANTERN


[HORNOR]

9b—SILVER FIXTURE—
DMIRAL'S QUARTERS

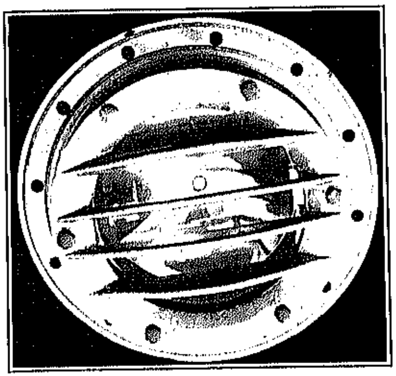
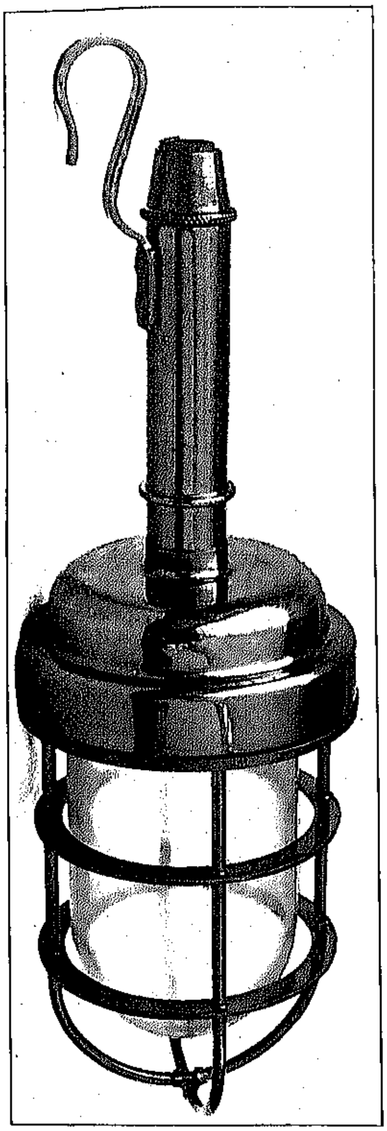
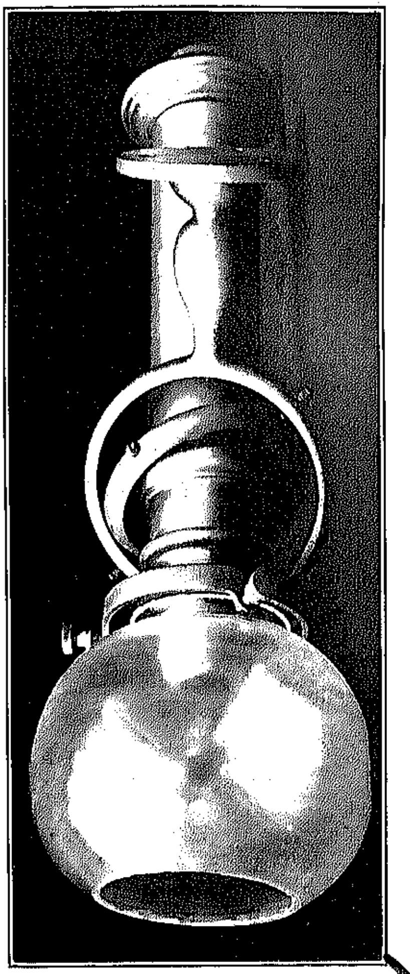

[HORNOR]

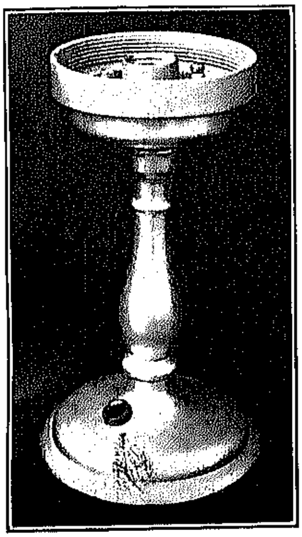
FIG. 9c—BULKHEAD BUNKER
FIXTURE



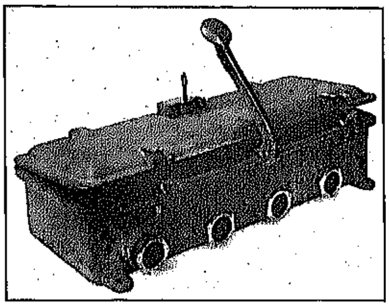
[HORNOR]
Fig. 9d—Water-tight Portable Lamp



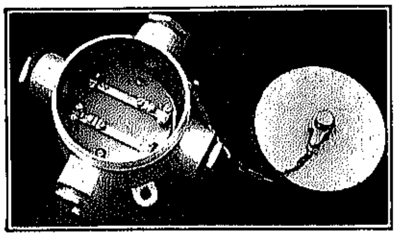
[HORNOR]
Fig. 9c—Bracket. Fixture



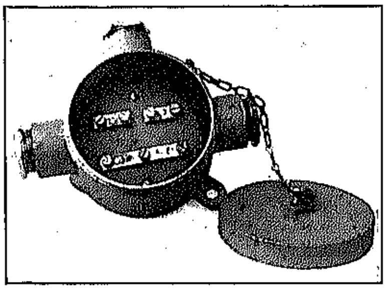
[HORNOR]
FIG. 9f—DESK PORTABLE



[HORNOR]
FIG. 9g—SELF-CLOSING DISTRIBUTION BOX



[HORNOR]
FIG. 9j—FEEDER JUNCTION BOX, 4-WAY



[HORNOR]
FIG. 9h—WATER-TIGHT BRANCH JUNCTION BOX—THREE-WAY

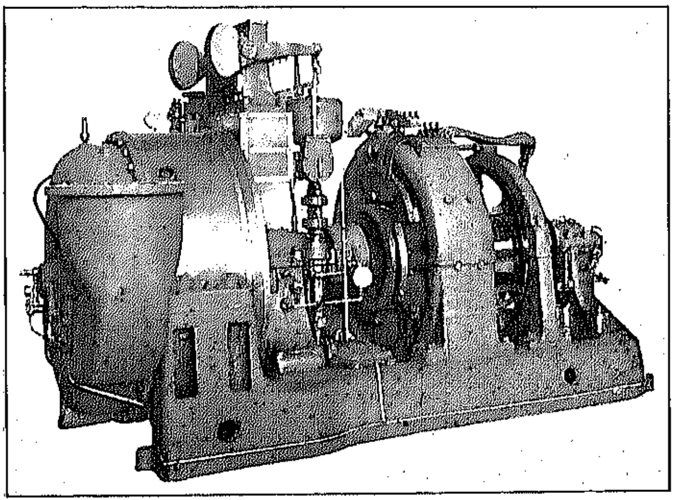
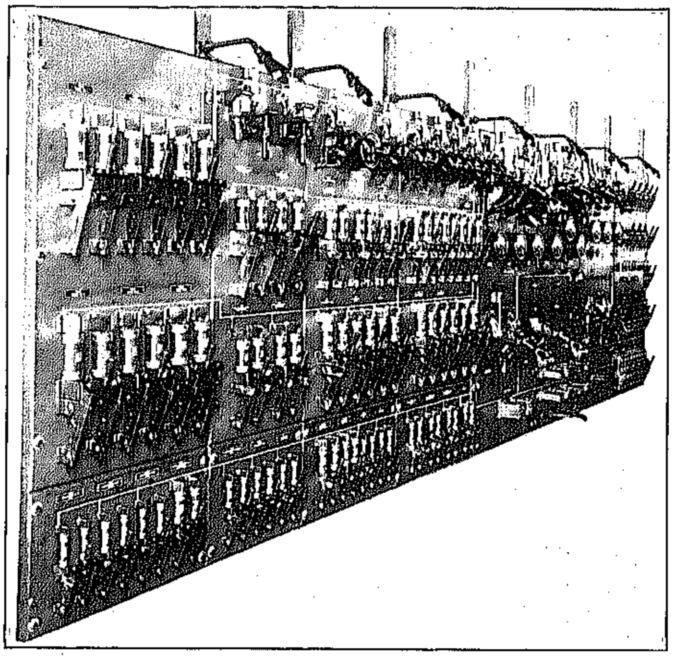
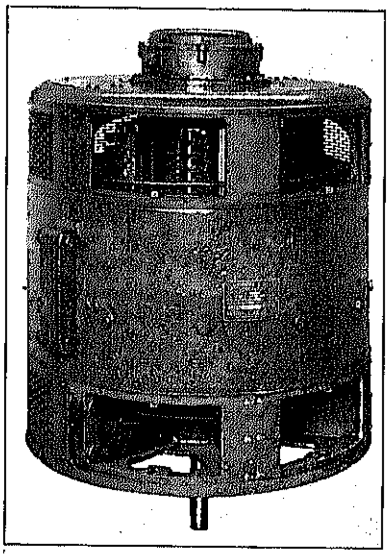


FIG. 12—375-KW. GENERATOR [HORNOR]



[HORNOR]

FIG. 13—MAIN DISTRIBUTION SWITCHBOARD



[HORNOR]

FIG. 14—BILGE PUMP MOTOR

No.	Equipment	Rated horse power	Total horse power
9	600-cu. ft. Ventilation Fans..............	4.	36.
9	1600 cu. ft. Ventilation Fans........	1.	9.
1	1600 cu. ft. Ventilation Fan	2.	2.
6	2500 cu. ft. Ventilation Fans...........	1.5	9.
24	2500 cu. ft. Ventilation Fans..........	2.75	66.
3	2500 cu. ft. Ventilation Fans..........	3.5	10.5
4	5000 cu. ft. Ventilation Fans	3.25	13.
6	5000 cu. ft. Ventilation Fans..........	6.	36.
2	5000 cu. ft. Ventilation Fans..........	6.75	13.5
7	6000 cu. ft. Ventilation Fans..........	3.75	26.25
5	6000 cu. ft. Ventilation Fans..........	7.	35.
2	8000 cu. ft. Ventilation Fans.....	5.	10.
6	8000 cu. ft. Ventilation Fans.........	9.	54.
2	10,000 cu. ft. Ventilation Fans....... ..	6.25	12.5
3	12,000 cu. ft. Ventilation Fans...	7.5	22.5
2	15,000 cu. ft. Ventilation Fans..........	10.	20.

As shown in the cable scheme for power distribution (Figs. 10 and 11) the feeders from the main distribution switchboards in some cases are led directly to the motor starting panel, in others they are branched into mains and in others they are led to special distribution panels. This latter is so in the case of the four-in. (101.6-mm.) and six-in. (152.4-mm.) ammunition hoists, the searchlights, and the 12-in. (304.8-mm.) turrets. The turret distribution panel is located on the revolving part of the turret and is encased in a water-tight steel box.

As shown by the illustrations, a variety of motor types is used, viz: open, semi-enclosed, fully enclosed, and enclosed-ventilated. The small motors up to 10 h.p. are regulated by simple starting and field control panels. Above 10 h.p.-drum controllers are employed. On the very large equipments performing special service and requiring 50 to 150 h.p., contactor control with dynamic braking is provided.

STEERING GEAR

The electrical equipment is designed as an auxiliary to the steam steering engine, operates through the same telemotor gear on a "follow-up" system, and furnishes only sufficient power to carry the rudder from hard-over to hard-over in 40 seconds, which is half the time requirement of the steam gear. The motor is of the commutating pole, open type, compound-wound, rated at 150 h.p., 400 to 600 rev. per min., 220 volts. The controlling appliances comprise a master controller and limit switch mounted in one case, a contactor panel and the necessary field and armature rheostats operated by the same. In the master controller are two cylinders provided with rings; these make electrical contact with plungers; one of these cylinders is for the controller, the other for the limit switch. Both cylinders turn freely on their supporting shafts. The controller cylinder operates through a connecting rod from the operating shaft of the steering gear. The limit switch cylinder operates through a sprocket chain from the main steering gear shaft. The differential gear, or "follow-up" device, is located between the two cylinders and is designed to turn the controller cylinder off by motion of the main shaft of the steering gear which turns the limit switch.

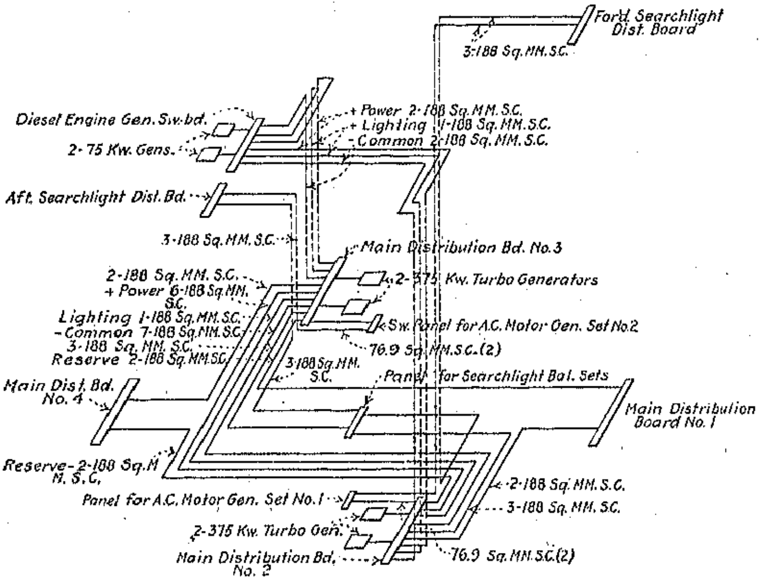

Forᵭ. Searchlight Dist. Board
3-188 Sq. MM. S.C.
Diesel Engine Gen. Sw.bd.
2-75 Kw. Gens.
+ Power 2-188 Sq. MM. S.C.
+ Lighting 1-188 Sq. MM. S.C.
- Common 2-188 Sq. MM. S.C.
Aft. Searchlight Dist. Bd.
3-188 Sq. MM. S.C.
Main Distribution Bd. No. 3
2-188 Sq. MM. S.C.
+ Power 6-188 Sq. MM. S.C.
Lighting 1-188 Sq. MM. S.C.
- Common 7-188 Sq. MM. S.C.
3-188 Sq. MM. S.C.
Reserve 2-188 Sq. MM. S.C.
2-375 Kw. Turbo Generators
Sw. Panel for A.C. Motor Gen. Set No. 2
76.9 Sq. MM. S.C. (2)
3-188 Sq. MM. S.C.
Panel for Searchlight Bal. Sets
Main Dist. Bd. No. 4
Main Distribution Board No. 1
Reserve-2-188 Sq. M M. S.C.
2-188 Sq. MM. S.C.
3-188 Sq. MM. S.C.
Panel for A.C. Motor Gen. Set No. 1
2-375 Kw. Turbo Gen.
Main Distribution Bd. No. 2
76.9 Sq. MM. S.C. (2)

FIG. 10—DIAGRAM OF POWER DISTRIBUTION

The latter strengthens the field of the motor when the rudder is displaced more than 10 deg. from the midship position. The mechanical connections are such that the motor will stop when the rudder has reached the angle for which the steering wheel has been turned. The motor field cannot be weakened until all of the accelerating contactors have closed, after which the controller will maintain full field until it has been turned through an angle corresponding to 3 deg. movement of the rudder from starting position, and intermediate field from 3 deg. to 5 deg., after which the motor will run at weak field until the rudder has reached 10 degrees from the midship position. Mounted upon the contactor panel are 10 armature contactors, two field contactors, one disk brake contactor, two counter e.m.f. contactors, an overload relay, a double-pole, fused, control switch, and a single-pole testing switch. The overload relay controls four of the five accelerating circuits whereby they operate, resistance is introduced into the armature circuit, and the field rheostat short-circuited so that the motor is protected against continued overload without being actually stopped. In this manner accidentally losing control of the rudder cannot occur. The limit switch is arranged to stop the motor at the 35-deg. position of the rudder. Dynamic braking is provided in connection with the electro-mechanical disk brake in order to provide prompt stopping. The rudder can be turned at slow speed throughout its travel, provided the steering wheel is turned slowly, thereby permitting the motor to turn the controller cylinder backward as fast as it is turned forward by the steering wheel. This may be accomplished while the controller cylinder moves back and forth between limits corresponding to 2.25 degrees motion of the rudder, as the motor will start with a motion of cylinder equivalent to 0.75 deg. movement of the rudder and the field will be weakened with 3 deg. similar motion.

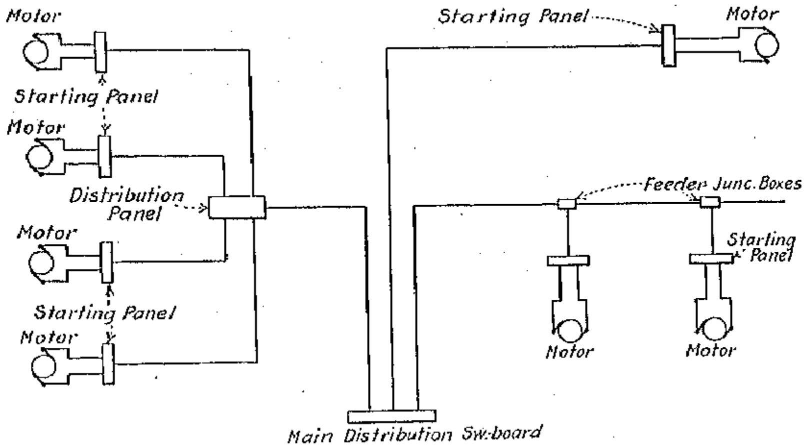
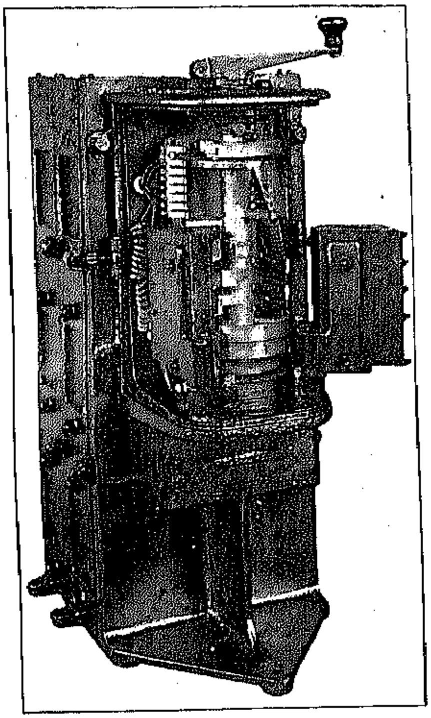


FIG. 11—CABLE SCHEME FOR POWER DISTRIBUTION

TURRET HOISTS

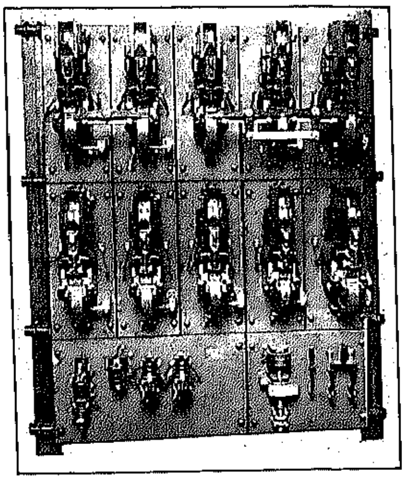
The turret turning gear and gun elevating gear are operated by constant-speed motors, and speed variations are accomplished by mechanical means. Ventilation blowers in the turrets are similar to the regular hull ventilation fans, except for increased pressure. The independent hoists complete the electric power equipment of the turrets. The main ammunition hoists are operated by hydraulic power and the electric hoists are provided as an auxiliary. Two upper hoists are fitted in each of the six turrets. These are operated by 7.5-h.p. motors. One lower hoist is fitted in each turret. One of these is operated by a 7.5-h.p. motor and the others by 12-h.p. motors. As these equipments are generally similar in their operation, only the 12-h.p. lower hoist will be described.

The apparatus consists of: a contactor panel upon which are mounted the accelerating contactors, overload relay, current-limit relay, and voltage relay; the master controller located at the bottom of the hoist; the emergency controller located at the top of the hoist; the limit switch and rheostats. By means of automatic interlocks on the contactors the connections are regulated between the master controller, limit switch and emergency or upper controller; so that upon turning the master controller to the "on" position the disk brake releases and the motor starts. When the hoist, therefore, reaches its limit in either direction dynamic braking is introduced and the motor stops. When the operator at the top of the hoist desires to stop the hoist he turns the emergency controller to the "off" position, the contactors operate automatically and stop the motor. If the limit switch is now left in an intermediate position the motor will automatically start when the emergency controller is turned to the "on" position. If the limit switch has been turned to the "off" position by the hoist then the motor will not start until the master, or lower, controller is turned to the first controller notch. In case of overload, the overload relay through the interlocks will open the contactors automatically and stop the motor. The hoist cannot be started again until the operator returns the master controller to the "off" position, which permits the plunger of the overload relay to drop. It is necessary to unlock the reversing cylinder of the master controller mechanically in order to use the hoist for lowering. The connections for this operation are so arranged that the accelerating contactors and current-limit relays are inoperative and suitable resistance introduced in parallel with the armature and a large current capacity resistance connected in series with the armature and starting resistance; by reason of which the



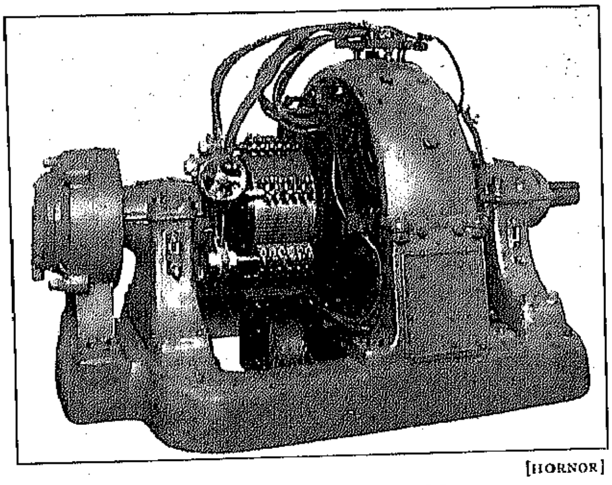
[HORNOR]

FIG. 15—BILGE PUMP MOTOR CONTROLLER



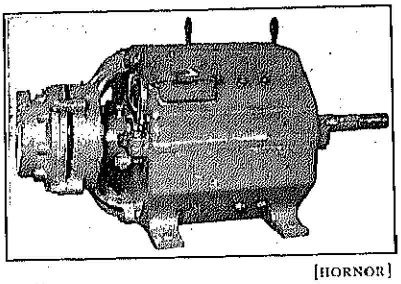
[HORNOR]

FIG. 17—CONTACTOR PANEL FOR STEERING GEAR MOTOR



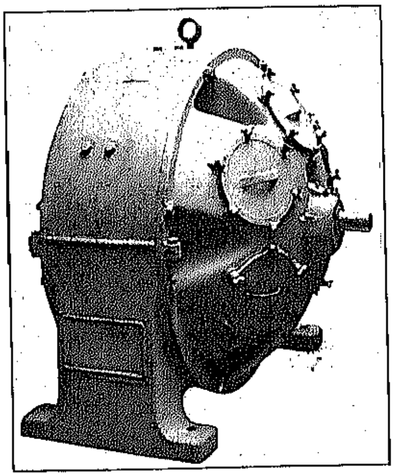
[HORNOR]

FIG. 16—STEERING GEAR MOTOR



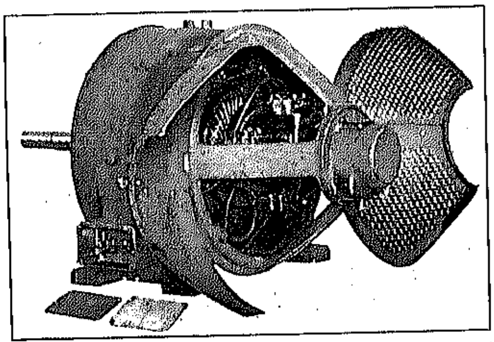
[HORNOR]

FIG. 18—BOAT BOOM MOTOR



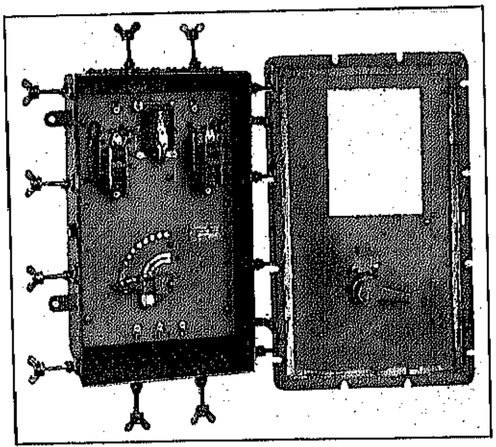
[HORNOR]

FIG. 19—FORCED DRAFT FAN MOTOR



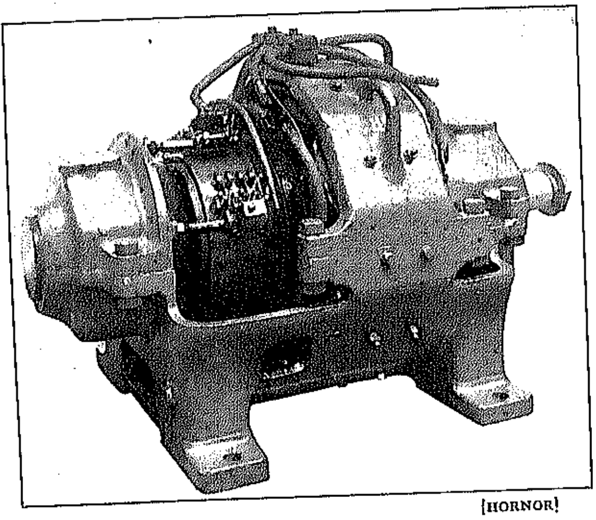
[HORNOR]

FIG. 20—HULL VENTILATION FAN MOTOR



[HORNOR]

FIG. 21—CONTROL PANEL FOR HULL VENTILATION MOTOR



[HORNOR]

FIG. 22—COALING WINCH MOTOR

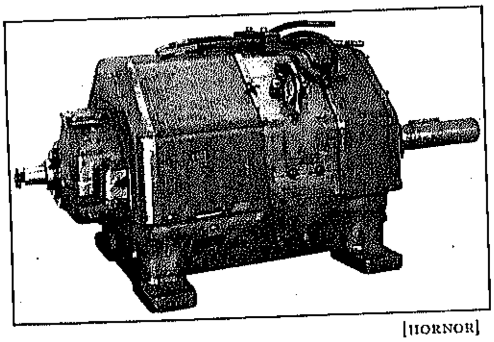


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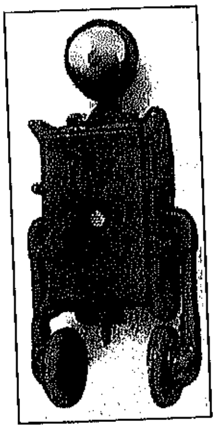
FIG. 23—ANCHOR WINDLASS MOTOR



[HORNOR]

FIG. 26—LOUD SPEAKING TELEPHONE, WATER-TIGHT

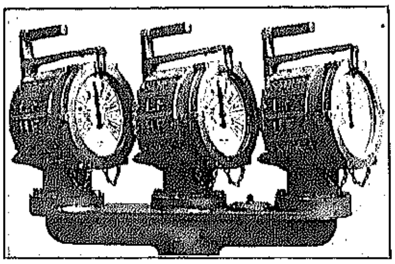


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FIG. 27—ELECTRIC ENGINE TELEGRAPH TRANSMITTER

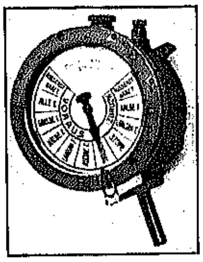

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FIG. 28—ELECTRIC ENGINE TELEGRAPH RECEIVER

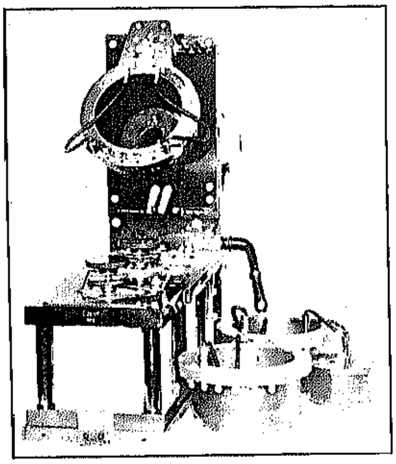

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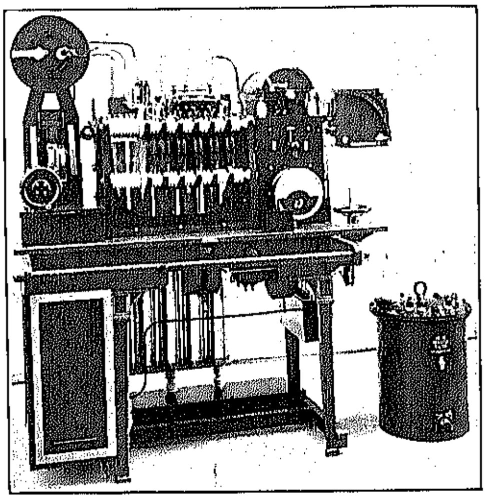
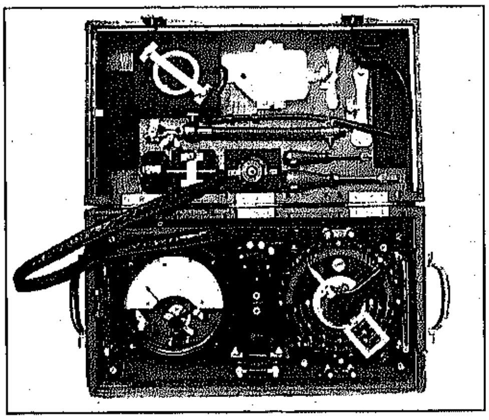
FIG. 31—WIRELESS TELEGRAPH RECEIVER



[HORNOR]

FIG. 31A—WIRELESS TELEGRAPH TRANSMITTER



[HORNOR]

FIG. 32—WIRELESS TELEGRAPH WAVE METER

hoist will lower slowly. Other functions lowering, are similar to those of hoisting.

ANCHOR WINDLASS EQUIPMENT

The electrical apparatus acts only as an auxiliary to the steam windlass and is designed to function at half the normal load of the steam gear. The outfit comprises a 100-h.p., 475-rev. per min., compound-wound, commutating-field motor of the open type which is equipped with a disk brake; two water-tight, drum-type, reversing master controllers, one mounted in the windlass room and one mounted on the weather deck; a contactor panel containing the accelerating contactors, a step-back relay, overload relay, a double-pole, single-throw disconnecting switch with field discharge clips, a small single-throw testing switch, and a low voltage relay. The control is semi-automatic, *i. e.*, the first three speeds are controlled by the master controller but beyond that the current-limit relays on the contactors will prevent them from closing until the current in each preceding one has been reduced to a predetermined amount, regardless of the position of the controller cylinder. The setback relay will open the contactors in case the load should be increased beyond that for which the set-back relay has been set, and it will introduce all of the starting rheostat except two sections, thereby reducing the current to about 25 per cent overload on the motor. The overload relay will be set considerably higher than the set-back relay, thus protecting the motor in case of excessive overloads. The overload relay is reset by bringing the controller to the "off" position. The armature and commutating field coils are permanently connected and consequently are reversed together. The low voltage relay prevents the equipment from starting automatically after failure of current, requiring the controller to be brought back to the "off" position, whereupon the circuit will be re-established.

ROENTGEN RAY OUTFIT

This equipment is arranged for supply from a 220-volt d-c. circuit. The following apparatus of German manufacture is furnished:

An induction coil with adjustable spark gage and three primary windings. The length of spark gap is 16 inches (40 cm.).

Two Gundelach X-ray tubes.

Two Burger-Central X-ray tubes with curved anticathode, air-cooled.

Two Bauer-Delta X-ray tubes with softening adjustment.

One three-part Wehnelt interrupter with one thin and two thick platinum electrodes.

One control switch panel.

The apparatus is located in the operating room adjacent to the sick bay. It is of interest because of the originality of the application.

MOVING PICTURE MACHINE

Like the X-ray outfit the installation of a cameragraph on a man-of-war is unusual. The outfit represents the very latest design of such machines and is of American manufacture. The apparatus is supplied by a 220-volt circuit and the films are rotated by an adjustable speed, 220-volt, d-c. motor. All the safety attachments required by the underwriters and those automatic devices necessary for smooth performance are provided. The apparatus is portable.

SIGNALING SYSTEMS

The third division of the electrical equipment is classified under the head of Interior Communication Systems, although a few of these are solely for exterior use. They constitute the means for the transmission of intelligence throughout the vessel and are responsible for its behavior when a component part of a military squadron.

The systems comprising this division are given in the following list and a few of the more important and unusual applications will be briefly described.

Call Bells.
Reply Signals for Mechanical Telegraphs.
Fire Alarm.
Electric Clock.
Shaft Revolution and Direction Indicators.
Electric Log Indicator.
Fuel Oil Indicator.
Ammunition Hoist Indicators.
Gun Firing.
Engine Revolution Order Telegraph.
Helm Angle and Steering Telegraph.
Engine Order Telegraph.
Fire Room Telegraph.
Turret Salvo.
Torpedo Defense Salvo.
Anchor Handling.
Coal Bunker Alarm.
Boiler Firing.
Boat Hour Gong.
Day Battle Salvo.
General Alarm.
Cease Firing.
Torpedo Firing.
General Telephone.
Captain's Telephone.
Fire and Engine Room Telephone.

Turret Telephone.
Fire Control Telephone.
12-in. (304.8-mm.) Fire Control Telegraph.
6-in. (152.4-mm.) Fire Control Telegraph.
Turret Danger Zone.
Turret Tell-Tale.
Azimuth.
Course Telegraph.
Gyroscopic Compass.
Pyrometer.
Anemometer.
Electric Whistle.
Wireless Telegraph.

These systems are supplied with power from two stations on the vessel, the forward interior communication room and the forward dynamo room. There are two central signaling stations, one forward on the upper platform deck below armor and the other on the gun deck aft. The vessel is further provided with two conning towers, one forward and one aft; two observation towers; and several gun control stations.

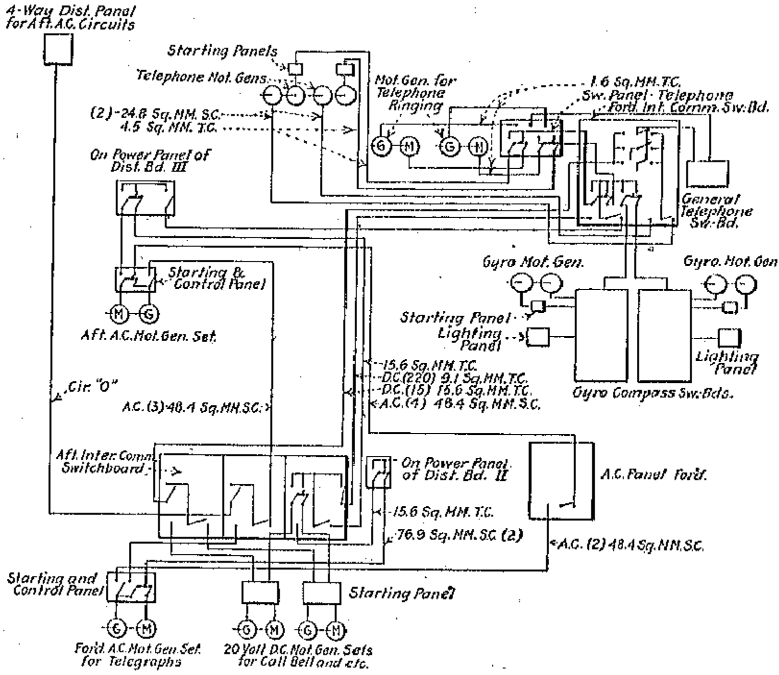

4-Way Dist. Panel for Aft. A.C. Circuits
Starting Panels
Telephone Mot. Gens.
(2)-24.8 Sq. MM. S.C.
4.5 Sq. MM. T.C.
Mot. Gen. for Telephone Ringing
1.6 Sq. MM. T.C.
Sw. Panel · Telephone
Ford. Int. Comm. Sw. Bd.
On Power Panel of Dist. Bd. III
General Telephone Sw. Bd.
Starting & Control Panel
M
G
Aft. A.C. Mot. Gen. Set
Gyro Mot. Gen.
Gyro. Mot. Gen.
Starting Panel
Lighting Panel
Lighting Panel
15.6 Sq. MM. T.C.
D.C. (220) 9.1 Sq. MM. T.C.
D.C. (15) 15.6 Sq. MM. T.C.
A.C. (4) 48.4 Sq. MM. S.C.
Gyro Compass Sw. Bds.
Cir. "O"
A.C. (3) 48.4 Sq. MM. S.C.
Aft. Inter. Comm. Switchboard
On Power Panel of Dist. Bd. II
A.C. Panel Ford.
15.6 Sq. MM. T.C.
76.9 Sq. MM. S.C. (2)
A.C. (2) 48.4 Sq. MM. S.C.
Starting and Control Panel
Starting Panel
G
M
Ford. A.C. Mot. Gen. Set for Telegraphs
20 Volt D.C. Mot. Gen. Sets for Call Bell and etc.

FIG. 24—DIAGRAM OF INTERIOR COMMUNICATION DISTRIBUTION

A number of these equipments operate on 220 volts direct current, supplied in duplicate from the forward and after main distribution switchboards. However, certain of the telegraph systems require 120 volts alternating current; others, such as the telephone system, clock system, call bell system, require 15 volts direct current; and the fire control telephone system requires 35 volts direct current. These transformations are accomplished by means of small motor-generators, usually supplied in duplicate. The a-c. motor-generators, which are rated at 18 kw. single-phase, 50-cycle, 120 volts, being of rather large size, are located one in each dynamo room. The a-c. control panel is located in one of the compartments constituting the forward central station. Supply to this panel is brought directly from the control panel of the after motor-generator set and, *via* the after interior communication control panel, from the forward motor-generator.

The 15-volt d-c. motor-generators are both located in the forward dynamo room directly below the after interior communication control panel, which contains a panel especially for this distribution. Thus the after interior communication switchboard contains three panels; one for the distribution of 220-volt d-c. circuits, one for the 15-volt d-c. circuits, and one for the 120-volt a-c. circuits. The forward interior communication switchboard contains two panels, one distributing 220 volts d-c. and the other 35 volts d-c. This switchboard receives energy from the two 35-volt d-c. motor-generators for the fire control telephone system and the two ringing motor-generators for the general telephone system. It also supplies 220-volt direct current to the two motor-generators for the gyroscopic compass system. The 220-volt busbars are energized directly

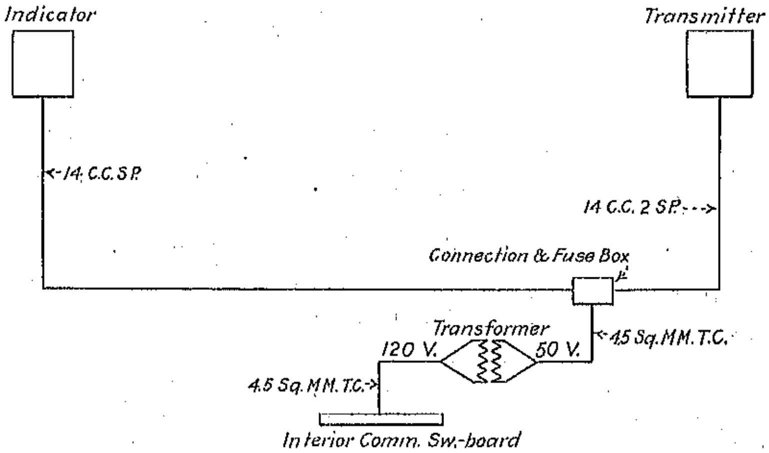


FIG. 25—CABLE SCHEME FOR INTERIOR COMMUNICATION SYSTEM

from the after main distribution switchboard, and also from the forward main distribution switchboard *via* the after interior communication switchboard. Every possible precaution has been taken to avert any failure of operation due to lack of supply or interruption of service. It is interesting to note that a diagram of the busbar connections is cut into the face of all switchboards and these grooves filled in with colored paint.

TELEGRAPH SYSTEMS

There are about 16 systems, such as engine order telegraph, course telegraph, etc., which are operated on the principle of an unbalanced circuit, *i.e.*, when the circuit is undisturbed no current flows. Thus a constant a-c. field, which changes its direction corresponding to the periods of the exciter current, induces currents in the armature coils. The armature of one motor—let us say transmitter—is wound with three interconnected coils and connected by three wires directly to the armature coils of the receiver motor. The power in the armature windings depends upon the rotative position of the armature coils in the field of force. If the armature of the transmitter and receiver have the same position relatively to the field then the induced e.m.f. would be of the same value and the wires between the two armatures would carry no current. If the armature of the transmitter is moved so as to unbalance the armature circuit then current flows in the armature windings, produces a torque, and the armature of the receiver turns to the same position. When this occurs the equalizing currents disappear, and with them the torque.

Any desired number of orders can be arranged for transmission, and any number of receivers connected to the transmitter without increasing the number of connecting wires. Five wires are needed for a simple circuit, two for the field and three for the armatures. For repeating instruments two sets of motors are employed. The transmitter motor is usually larger than the receiver motor, due to the fact that it often operates a number of receivers. Energy is delivered to this apparatus from a 120-volt a-c., single-phase, 50-cycle motor-generator, *via* a step-down transformer, which lowers the potential to 50 volts.

These instruments have a large and varied use, as shown in the above list; sending orders from the bridge to the engine room, indicating the position of the rudder direct from the rudder stock to the navigator, giving orders for a change in course of the vessel, transmitting emergency orders from the bridge or conning tower when the regular steering gear is deranged, ordering small changes in speed when in squadron maneuvers, furnishing signals from the gun-firing station to each and every gun, and many other purposes too numerous to record.

PYROMETERS

There are six boiler rooms on the vessel from each of which are led three uptakes to the two smoke-stacks. Each uptake is provided with a base metal thermocouple pyrometer. Nine of these eighteen couples indicate at two stations, one in the forward boiler room hatch, and one in the after boiler room hatch. The indicators are of the low-resistance type mounted in special water-tight cases and provided with a nine-point switch for the purpose of reading each uptake temperature. The thermocouples are formed of a nickel alloy wire and capable of constantly measuring a temperature of 1800 deg. fahr. and intermittently up to 2000 deg. fahr. The head of the couple is specially arranged for mechanical protection and water-tightness.

ANEMOMETER

This is an unusual equipment for battleships. The apparatus consists of a transmitter comprising a pivoted rotative vane carrying at one end a fan. The vane in orientation and the fan shaft through a worm gear translate their movements by means of electrical contacts. Thus the velocity and direction of the wind will be recorded. The instrument for the *Moreno* was ordered from France and registers sixteen directions. The direction and velocity of the wind are checked off by the pen on the registering chart in increments of one mile (1.609 km.), every time the wind changes. The maximum record for the chart is 62.13 miles (100 km.) and when the pen reaches this point it automatically returns to zero. The transmitter is located on the top of the forward cage mast and the registering apparatus in the central station. It requires five wires between transmitter and register and operates on approximately four primary cells.

ENGINE REVOLUTION AND DIRECTION INDICATOR

Each of the three main turbine propelling shafts is equipped with a contact-maker for indicating the number of revolutions, a contact-maker for indicating the direction of the shaft, both located in the engine room; a synchronizing clock and indicator also located in the engine room near the working platform; and three indicators located in the pilot house, forward conning tower, and central station. Eight wires are required to each indicator, three for the direction tell-tale and five for indicating the speed. Energy for operation is taken from the 15-volt busbars of the after interior communication switchboard. This apparatus is manufactured in Italy and is known as the Molinari speed indicator.

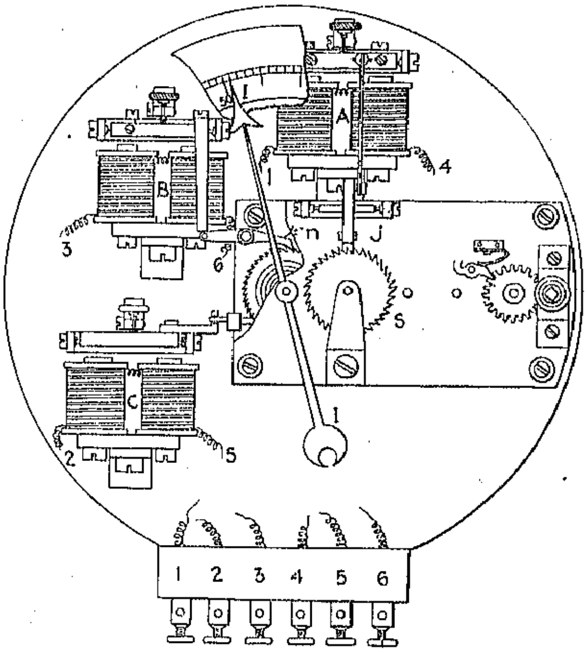


FIG. 29—INTERIOR VIEW OF SPEED AND DIRECTION INDICATOR

The direction contact-maker is a simple make-and-break contact operated directly from the shaft through chain and gearing.

The revolution contact-maker consists of a lignum-vitae cylinder carrying three brass sectors made flush with the periphery. It is located near the main shaft and arranged to turn at the same rate of speed. It is provided with two brushes insulated from each other and mounted on spring blocks.

The synchronizing clock controls the make-and-break contacts of the revolution contact-maker so that these impulses may be interpreted by the indicator in measured time. A flat commutator provided with three segments insulated from each other is mounted in the clock and traversed by a metal brush. In this particular installation the "long-make" segment is designed to be maintained for a period of 15 seconds and the two "short-make" segments two seconds each. In this manner the speed during the fifteen seconds previous to reading the indicator is correctly measured.

The indicator consists of a train of clock gears actuated by a spring. Fig. 29 shows an internal view of the mechanism and Fig. 30 represents a plan of the clockwork.

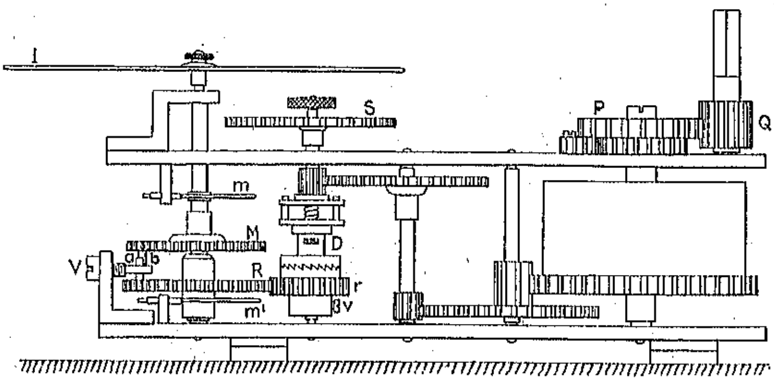


Fig. 30—Clockwork Mechanism—Speed and Direction Indicator

Wireless Telegraph

This apparatus is of German manufacture and known as the Telefunken "quench-spark", variometer system. The set is rated as 5 kw. in the antenna with a primary energy of 8 kw. The advantage of the variometer principle is that it permits of a variable range of wave length, which range may be chosen between 600 meters (1968 ft.) and 2000 meters (6560 ft.), depending upon the capacity of the aerial.

The motor-generator set is supplied with a double feeder from both of the main distribution switchboards. This set consists of a 220-volt d-c. motor of 18 h.p. and an a-c. generator rated approximately 8 kw., 500 cycles, 220 volts. The normal speed of the set is 1500 rev. per min. but can be varied for the purpose of altering the spark frequency and thereby the note of the transmitter about 20 per cent in either direction. The pitch of the transmitter note can also be adjusted very exactly by varying the field of the generator.

A straight core transformer steps up the 220-volt potential to 8000 volts. A primary choke coil is connected in series with the low-tension winding of the transformer. When the large capacity (5 Leyden jars) is used, the choke coil is used as a quenching coil in parallel with the emergency key, *i.e.*, this coil prevents severe sparking when the emergency key is brought into action. A secondary choke coil is connected in series with the high-tension winding of the transformer. This choke coil affords not only protection against high frequency, but also provides resonance between the transformer and the excitation current.

The closed oscillatory of the transmitter consists of a battery of four or five Leyden jars of a capacity of from 10,000 to 12,000 centimeters each (0.01 to 0.013 microfarad). Four or five of these jars can be connected by means of a sliding contact as may be required. Next there is provided a 16-part quenched spark gap which is air-cooled (maximum number of gaps to be used, 12) and a primary variometer. This latter consists of three fixed and two movable coils which can be connected either in series or parallel by means of a switch. This gives a variable inductance in the ratio of 1 to 16. The variometer scale is graduated so as to enable any wave length between 600 meters (1968 ft.) and 2000 meters (6560 ft.) to be adjusted in a moment.

The antenna will be of the L type, slanting from the foremast to the mainmast. The direct distance is 196 ft. (59.8 m.) and the hypotenuse 206 ft. (62.8 m.). The antenna capacity has been fixed to absorb an oscillatory energy of 5 kw. without loss, providing for the above stated wave lengths. In this circuit is the antenna variometer, which consists of six fixed and five movable coils arranged in two groups. By means of the scale and the corresponding curves, waves up to 1450 meters (4756 ft.) can be adjusted. For waves above this a lengthening coil is connected in series with the variometer which increases the wave range to 2000 meters (6560 ft.).

For receiving purposes a crystal detector is used It is claimed that this has the property of converting the high-frequency currents flowing through it into unidirectional currents. Therefore, it operates without any auxiliary e.m.f. and the receiving apparatus does not contain a local battery. It is also claimed that a very high degree of sensitiveness is shown when receiving at long distances. By its use the connections are also very much simplified. Underneath the variable receiving transformer is a two-pole change-over switch marked "long waves" and 'short waves.' When the switch is on the position "short waves," the connections are as follows: Antenna, lengthening coil, variable condenser, earth or counterpoise. When the switch is on the position "long waves," the lengthening coil and variable condenser are connected in parallel to form a closed oscillatory circuit. The antenna now is connected to one pole of the condenser and the earth or counterpoise to the other.

With both methods of connection, the energy is transferred from the low-tension transformer coil which is in series with the antenna into the high-tension transformer coil. The latter forms, with the detector, an aperiodic circuit. This requires only one circuit to be tuned, viz.—for "short waves" the antenna circuit and for "long waves" the closed oscillatory circuit. Means are also provided for increasing the capacity of the receiver through an intermediate circuit whereby disturbances from other stations and atmospheric discharges may be avoided.

The design of this apparatus is such as to provide every means for the protection of the apparatus and operator from high tension. Behind the vertical frame of the receiver is a high-tension terminal and the high-tension switch, to which the leads from the antenna and the transmitter are connected. By this means the antenna is connected to the receiver and the transmitting circuit automatically interrupted.

This equipment has a guaranteed range of 1000 kilometers (621.3 miles) by day and 2100 kilometers (1304.7 miles) by night. That these guarantees will be exceeded in practise is seen in the report of trials on the sister ship *Rivadavia*, where communication was held between Boston and Colon, a distance of approximately 2000 miles (3218 kilometers).

Gyroscopic Compass

This apparatus is of German manufacture and is named, after its designer, the Anschütz gyro-compass. The design is based upon scientific principles laid down by the famous French philosopher Foucault. He arrived at the conclusion "that any gyro with only two degrees of freedom, *i.e.*, free to move in two planes only, will at any place on the earth's surface, other than the two poles, tend to set itself with its axis of rotation parallel to the axis of the earth itself, by reason of the relative rotations of the two bodies."

The practical value of this mechanism depends upon two essential points: the oscillations must be effectively "damped" and the suspension must be as nearly frictionless as possible. If the gyro be considerably deflected from the meridian line it will swing for a very long time and in this condition many new forces are brought into play. In this compass the movement of air set up by the gyro-motor not only provides ventilation for the motor but also enables "damping" of the oscillations. A small rectangular outlet for the air is cut in the gyro case, the space in the base of the binnacle is designed so that the air blast will be free from air currents in the casing, and thus the forces tending to tilt the gyro from the horizontal are opposed.

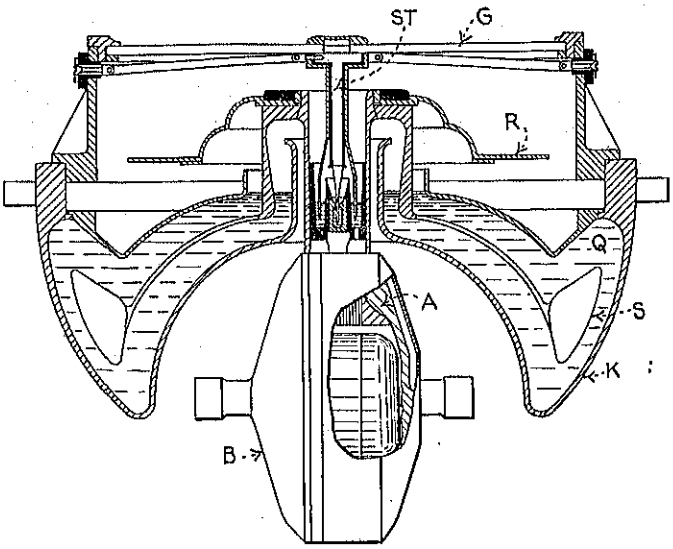


FIG. 33—SECTIONAL VIEW OF GYROSCOPIC COMPASS

As will be seen in Fig. 33, the complete gyro with motor casing, etc., is suspended by means of a circular, hollow, steel float in a bath of mercury. The mercury bowl is supported on gimbals in the same manner as any ordinary magnetic compass. The compass card is directly attached to the float and gyro and the gyro axle is directly under the north and south points of the card. The gyro always points due north and south. "In order to keep the whole floating system central a steel stem is fixed centrally in the top glass and the lower end of the stem dips into a small mercury cup carried on the top of the float. A similar connection is effected by a steel tube mounted concentrically with the stem and a second mercury cup. These two sets of connections are electrically insulated from one another and from the general metal portions of the apparatus. These two connections carry two phases of a three-phase current to the motor of the gyro; the third phase reaches the motor through the mercury bowl, mercury and float. The motor of the gyro consists of a very small three-phase motor, the stator of which carries the windings, so that all the connections can be rigidly made. The rotor is rigidly fixed into the inside of the gyro flywheel itself." Special nickel steel is used throughout and the axle is supported on ball bearings of specially hard steel.

The master compass receives its energy from duplicate motor-generators. The motor-generator transforms the 220-volt direct-current to three-phase alternating-current at 120 volts and 333 cycles. The alternator has 16 poles and runs at a normal speed of 2500 rev. per min. Therefore the gyro motor, which has two poles, runs at approximately 20,000 rev. per min. A control panel is provided upon which are mounted meters, switches, fuses, etc.

The master compass is arranged so that the mercury bowl may turn without any work being thrown on the gyro. The design is such that the mercury bowl always "follows" the movements of the gyro. This is only apparent, as it is the ship and binnacle that move. When the ship turns, a corresponding movement is imparted to the mercury bowl. The compass card of the floating system carries a small contact ball which is in contact with one phase of the three-phase supply. Attached to the mercury bowl but insulated from it are two semi-circular contact bands. Any movement of the ship will bring the contact ball of the floating system into contact with these semi-circular bands. These contacts control a two-phase reversible motor mounted on the gimbal rings which when contact is made rotates the mercury bowl until the contact is broken and the circuit to reversible motor is open. This motor, as just described, receives its two-phase current from two of the three phases driving the gyro-motor.

The transmission of these motions to the receiving compasses is accomplished by means of a commutator mounted on the axle of the reversible motor. This commutator is constructed half of glass and half of silver. Four sets of brushes are arranged around the commutator at a distance of 120 deg. Connections are made from each of these points to each receiver. The motor of the receiver has a stator similar to that of a star-connected three-phase motor. The star point of the stator is connected by a brush to the shuttle armature. This synchronizing arrangement is claimed to repeat these movements with an accuracy of one-sixth of one complete revolution. The receiver motor is operated by direct current through a special resistance which acts like a potentiometer resistance and which branches the direct current at 140 volts. The supply of direct current is controlled by the same switch which controls the alternating current so that any failure of the supply will not throw the receiver out of synchronism. The receiver motors are geared to their outer compass card in the same ratio as the reversible motor of the master compass is geared to the mercury bowl.

General points of interest regarding this device may be summarized as follows:

Peripheral speed of the gyro is 500 ft. (152.5 meters) per second or 340 miles (547.06 km.) per hour.

The air friction is so great that it absorbs 95 per cent of the power of the gyro-motor.

The directive force on the gyro-compass is approximately 15 times as great as a magnetic liquid compass, free from all disturbances.

The gyro-compass, unlike the magnetic compass, points to the true north pole of the earth.

Directive force diminishes as the poles of the earth are approached, because of the higher latitude. Therefore the actual distance moved by the gyro (in space) in a given time is smaller. No directive force exists at the poles. Every line there is a meridian.

The angular momentum about the axle of the gyro is always 100,000 times, and sometimes 1,000,000 times, as great as the component of the angular momentum due to precession.

The following numerical data obtained from an actual instrument may be of interest.

Righting coefficient at the equator	20,190 dyn. cm.
Moment of inertia	404 x 10^7 g. cm^2
Period of damped oscillation	4,110 seconds
Period of undamped oscillation	3,080 seconds

Conclusion

This equipment is the largest and most costly ever installed in this country, comprising 3000 electric lights, 4000 rated h.p.

and approximately 76 miles (122.3 km.) of cable. It is a noteworthy engineering achievement in that it was a departure from American practise in the use of 230 volts; in the employment of lead-covered, steel-armored, conductors; in the application of 220-volt tungsten lamps; in the use of electricity for the purpose of steering the vessel, operating the anchor, and the bilge pumps; and many more advances in the application of electrical power. The result has been fruitful to the American manufacturer in that he is now prepared to furnish standard 230-volt apparatus designed for use on shipboard. This equipment also stands as a practical solution of the many problems involved and as a working comparison with previous equipments.

DISCUSSION ON "ELECTRICAL EQUIPMENT OF THE ARGENTINE BATTLESHIP 'MORENO'" (HORNOR), PHILADELPHIA, PA., OCTOBER 12, 1914.

H. L. Hibbard: I should like to know if the author could tell us something about the results of the tests on the electrical equipments which he pointed out as particularly novel and new, for instance, steering gear, anchor windlass, bilge pumps and ammunition hoists. All those are more or less novel, and I thought perhaps he could give us some actual data from this ship or possibly from her sister ship.

Maxwell W. Day: I think there is a decided advantage in the 220-volt system, as far as the installation of the wire is concerned and also in the size of the controlling appliances, and also to some extent because of its effect on the design of the motors, especially in the larger sizes where commutator space can be saved, but, on the other hand, the motors require more turns, taking a greater amount of waste space for insulation and a greater use of commutating poles, so that for a larger number of the motors there is no saving in weight or expense.

The question of operating searchlights by balancer sets or by other means is something of a problem. It is not extremely easy to determine whether it is better to put in balancer sets and use the rheostats or to use that type of generator which will give practically a constant current. With the 125-volt system there is no particular advantage in this type of generator, because its efficiency is not as high as that of other types, so that there is considerable loss in the machine itself, and the difference in using a rheostat for 125 volts to steady the arc, which might take 65 volts, or the use of a motor-generator set, does not show any great advantage for the motor-generator when we take into account the weight to be carried on the ship, although there might be cases in which the heat developed on the rheostats would be sufficiently objectionable to cause a decision in favor of the other arrangement. But when you come to 220 volts, the case is somewhat different, and in some navies special motor-generators, that deliver practically a constant current and require no steadying resistance for the arc, have been quite extensively used.

The steel switchboard with the instruments insulated from it is German practise. It seems to have some advantages, but, of course, the question of insulation is more difficult than it is with a slate base or panel made entirely of insulating material. But some troubles that have been experienced with slate led the United States Navy to look for other substances, and on motor control panels the use of ebony asbestos wood in place of slate is becoming more extensive. The use of alternating current for the interior communication system is also a German practise, although the Germans use direct-current apparatus also. I do not suppose the experience on the Argentine ships has been sufficiently extensive yet to decide on the relative merits so far as these ships are concerned.

The question that Mr. Hornor raised, of continuous waves as against a spark system of wireless telegraphy, is one of interest and the very successful results that have been obtained with the continuous wave system, both when developed by the arc and by high-frequency generators, have led to the desire to make use of some such system on smaller outfits, such as those used on vessels. But in the first place, there is a little difficulty in conveniently obtaining the short waves from the arc system, and to build a small high-frequency generator for short waves, is very expensive. Further, I understand that the short continuous waves are subject to a greater absorption in the atmosphere than those of the spark system, so that it seems rather doubtful to me that the continuous wave system will be extensively used for shipboard practise, at least in the near future.

I might say a word about the steering gear. As Mr. Hibbard knows, we have not advocated the contactor system for large equipments, but this particular case being one of 220 volts and of comparatively small power, it seemed to come within that range where contactors could be used with satisfaction. This particular system is not exactly what is being used in the United States Navy as regards the follow-up device. The United States Navy does not use follow-up devices, so that when the steering switch is turned to the right or left, the rudder moves to the right or left as long as the switch is left in that position or until the limit switch cuts it off, while on the earlier systems of electric steering gear, the amount of motion of the motor depended upon the amount of movement of the steering wheel or steering lever. It is rather difficult to make an electric follow-up device, and so in this case, and also in order to avoid adding to what is already an extensive electric equipment, the electric connecting leads between the steering gear itself and the steering stations were omitted and the control is operated by means of the same wire rope or hydraulic telemotor that operates the steam valve, the change-over connections being made in the steering room.

The *Moreno* has not had its trial trip, so that the tests at sea on this gear have not yet been made, and the final equipment on the *Rivadavia* has not had its full test, so that at present no information is available concerning the amount of power required or the general operation.

G. A. Pierce, Jr.: The wiring and the method of installation described were unique in this country and at the time this installation was designed. As Mr. Hornor stated, changes have been going on from time to time from a conduit system, which is not to be desired in any respect, and has been looked upon with suspicion since the early days when the change was made from a wooden molding to conduit. I think there will be no occasion in the future to return to the conduit system, so that as regards the reduction in weight and space and also the increased facilities for inspection, the present form of construction in the *Moreno* is an advancement.

In the distribution of energy we find the same method that has always been employed in this country, that of separate dynamo rooms, with interconnecting bus feeders, necessarily large switchboards, a multiplicity of circuits of small cross-section paralleling each other for great lengths, with a corresponding number of protective devices, and numerous large and cumbersome hand starting devices for motors. The installation of 38 lighting circuits for a total of 3000 lights, or an average of 80 lights per circuit, and the use of 76 miles of wire in the installation of this size, is a continuance of past practice, the advantage of which has long since been questioned in this country.

While there are some innovations in the application of electricity on this vessel, the extreme application is not apparent. The communicating and lighting system compares with vessels of the same dimensions built in this country, and by a comparison of the power installation with other vessels we find but few exceptions, viz., windlass, fire pump, oil engine pumps, electro-mechanical hammer, ozonators, athletic horse, and moving picture machine. There is also in use a power system which appears to have been advisedly omitted in vessels built in this country, that is, the electric forced draft blowers. Since the successful construction of small steam turbines has been accomplished, the installation of electric motors for forced draft blowers results in a waste of space, weight and economy. While we desire to see the unlimited use of the electric motor, it is the speaker's opinion that this consideration will apply to all auxiliaries within the zone of the boiler and machinery spaces, where power is available direct from the boilers without transformation and control of the power is so extremely simplified.

In 1902, when the Russian battleship was constructed in Philadelphia, we had an electric steering gear, electric bilge pumps, ash hoists, and electricity in almost all of these features, with the exception of the windlass, fire pumps, oil engine pumps, electro-mechanical hammer, etc., which at that time had not been invented, or were not in use anywhere.

The use of 220 volts, double the voltage previously used, does not result in one-half the cost of wire as would be indicated, but only in the saving of three-tenths, with very little difference in the cost of wiring appliances and practically no difference in the cost of apparatus or labor for installation. The saving in weight follows very closely the same proportions as the cost of material, and when the additional cost and weight of balancer sets with wiring and additional protective devices and switchboard equipment for the control of searchlights is considered, the advantage of this increase in voltage is questionable, particularly in view of the advisability, since alkaline storage batteries have become a commercial success, of installing storage batteries as auxiliaries for lighting and power for each battle unit.

The interior and exterior means of communication of information on this vessel are complete. The ever-increasing growth of this system in a battleship may, however, necessitate its remodeling in a very few months, as it is upon these systems the vessel must depend for its existence. If ready for action its presence must not be known until within range and if caught unawares or disabled it must attempt to escape and the vessel's own smoke or absence of it is employed for this purpose. We have recently learned of an invention to indicate automatically in any part of the vessel the color of the smoke emitted from the stack, and no doubt this system will be added in the near future to the ever-increasing means of communication on naval vessels.

Mr. Hornor has raised some question about the 220-volt lamps. Since the 220-volt tungsten lamps have been put on the market, we have been installing them in our shops, installing them on the bottom of cranes, and if there is anything that gets more vibration and shake than the bottom of a shop crane, it will hardly be found on a battleship.

As regards slate switchboards, I quite agree with the move our Government has made in the installation of composition in place of slate.

There appears to be no more necessity for duplicate dynamo rooms than for duplicate engine rooms. We believe that in the power plant of the future battleship there will be a number of units and a switchboard for supplying power for propelling the vessel and for all auxiliaries and lighting. The lighting and power for a deck or watertight section would be supplied from a common feeder with protective devices only at the apparatus, thus reducing weight, space and the cutting of bulkheads. All motors would be started either by contactors with a master controller or by automatic starter with a push button, depending upon the size and use of the motors. Lighting and power of each battle unit and indispensable auxiliary, such as steering gear, would be supplied by individual storage batteries of capacity for battle, thus reducing the size and increasing the efficiency of power installation.

We believe an installation of this character, in any or all of its features resembling the solution of the electric power engineering problem in large power stations on shore, and having the additional reserve for battle conditions at sea, to be not only a departure, but a decided advantage in economy, weight and space in comparison with any marine installations at the present date. Omitting the feature of electric propulsion, it is my opinion that the present practise can be improved upon by combining the dynamo rooms, combining and reducing the lighting and power circuits, using automatic starters and installing alkaline storage batteries, as previously stated.

Elmer A. Sperry: Mr. Hornor has given us a valuable paper. We find in the last paragraph on page 1588 "that any gyro with only two degrees of freedom, *i.e.*, free to move in two planes only," can be used as a compass. Now that is perfectly true; but that compass will only operate on land. When we take such a compass and put it on board ship, where it is subjected to all sorts of movements and motions, we encounter many real problems. These are due to the fact that the compass must of necessity be built pendulous, be supported in a Cardan or gimbal mounting, that it is subjected to acceleration and retardation pressures of the ship on which it is mounted during all sorts of maneuvers and changes of heading of the ship.

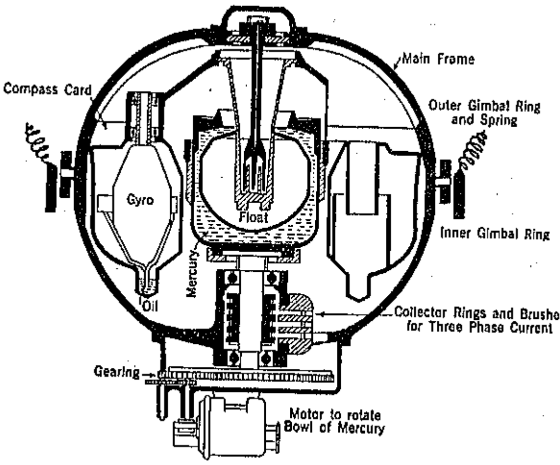

Main Frame
Compass Card
Outer Gimbal Ring and Spring
Gyro
Float
Inner Gimbal Ring
Mercury
Oil
Collector Rings and Brushes for Three Phase Current
Gearing
Motor to rotate Bowl of Mercury

FIG. 1—SECTIONAL ELEVATION OF ANSCHÜTZ COMPASS HAVING THREE GYRO. WHEELS

The compasses with which the Argentine battleships are equipped were purchased in 1910 or 1911 from a German manufacturer and contain one 6-in. gyro spinning at about 20,000 rev. per min. This was hung pendulous within an annular mercury bowl and was found to give serious deflections in azimuth, resulting from acceleration and retardation pressures and movements of the vessel referred to. No compasses with a single gyro wheel have been built by this concern for the past two or three years, but they have developed a new and very interesting compass containing three gyro wheels set at different angles to each other and coupled by certain links and bell-crank levers, pitman, etc., all the gyros being provided with centralizing springs, and they have adopted a follow-up system substantially similar to the one shown and described in a paper* on this sub-

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*H. C. Ford, *The Electrically Driven Gyroscope in Marine Work*, this volume, p. 857, Part I.

ject read before the Institute last June—see Figs. 7 to 15.

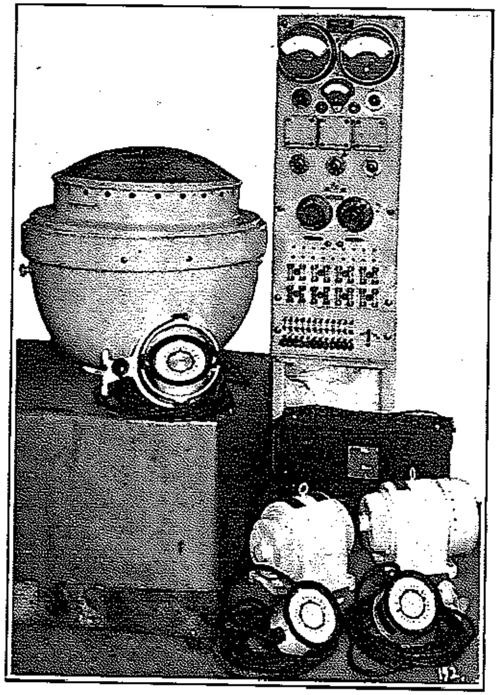
Inasmuch as no representation of this German product has been published in our annals, I am showing herewith, Fig. 1, a vertical section through the machine, giving a view of two of the three gyro wheels, three gyros being located equidistant around the circle. Each of these gyro wheels, it is stated, requires 1.1 amperes per phase at 120 volts, with a three-phase alternating current having a periodicity of 335 per second—in all, 3.3 amperes per phase. This is somewhat in excess of three times the current required by the American-made machine. The combined directive power, or useful function of this three-gyro compass is, however, only about 5/22 of that of the American-made machine.

Recent progress in adapting the gyro-compass to battle conditions has enabled the United States Navy to utilize features which do not seem to be present in any other navigation apparatus; among these is the fact that constant corrections which are found to be due to speed and course are automatically neutralized, giving all readings exactly on the true geographical meridian. Moreover, the military value of the apparatus adopted by the United States Navy is considerably increased, due to the fact that if the current supply cables are shot away or the current supply ceases for any reason the compass will continue to give true meridional readings with a high degree of precision for from one to two hours, instead of immediately initiating a wide-angle swing from the meridian. Also, each acceleration or retardation pressure received by the compass from the ship is made to introduce a primary force exactly balancing the disturbing factor, which latter is very powerful and would otherwise swing the compass away from the meridian.

The master compass is never used upon the bridge or in any of the major helmsman or steering positions, but is down in a position of safety below the water line and protected deck of the vessel. The azimuth, however, is required at distant points and is supplied by repeater compasses electrically connected to the master, reproducing the azimuth to the accuracy of a very slight fraction of a degree and with practically zero time lag. The American equipment has a unique feature consisting of means for synchronizing all or any of the distant repeaters and bringing them into exact harmony with the master, rather than trying to do it by telephone at each individual repeater.

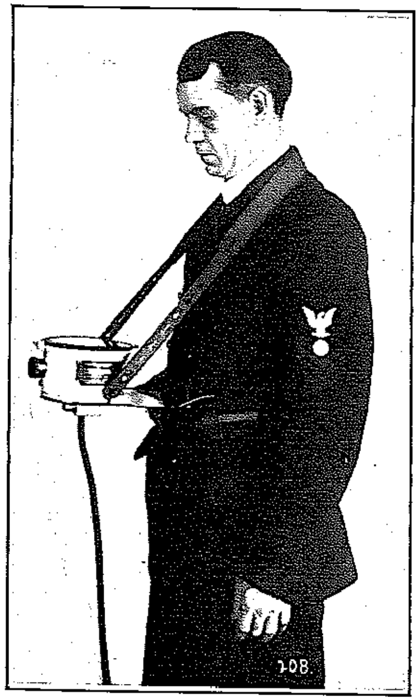
Another unique feature is an independent device connected with the master compass, giving extremely accurate indications as to whether or not the master compass is on the exact meridian. Coupled with this is an alarm system which gives automatic and vigorous notification if for any reason the master compass is off the meridian even a fraction of a degree.

We have heard a great deal about the performance of submarines in the present war. This performance is all the more



[SPERRY]

FIG. 2—AMERICAN GYRO-COMPASS EQUIPMENT FOR SUBMARINE



[SPERRY]

FIG. 3—PORTABLE GYRO-COMPASS REPEATER

interesting owing to this being the first opportunity that this new form of craft has had to exhibit its powers in actual warfare. In this connection a photograph of the entire gyro-compass equipment of one such submarine might be of interest. Fig. 2 reproduces a photograph of the equipment of the English submarine *E*-9, which is reported to have performed some very startling feats near Cuxhaven at a considerable distance from its base, to which base the submarine again safely returned after, it is reported, having inflicted considerable damage on the enemy. The illustration shows the equipment which had been installed some six days prior to this performance. One of the repeater compasses of this equipment is provided with a long flexible cable and is portable (see Fig. 3), being capable of use in various parts of the ship, especially at the discharge valve of the torpedoes. The great precision with which the exact gyro azimuth of all periscopic observations may now be determined and also the high degree of precision with which the ship may thereafter be directed, gives assurance of accuracy of torpedo fire never heretofore attained, and probably unattainable by any other means.

I wish to express my great appreciation of Mr. Hornor's paper, which has gone into so many interesting details of these great ships which America is certainly proud of having built for our American neighbors.

H. L. Hibbard: After Mr. Sperry's gyroscopic oscillations, a discussion on some of the other points will perhaps seem rather commonplace, but I should like to make a few remarks on some of the things which Mr. Hornor outlined.

On the voltage question, there is, of course, a gain in the size of conductors and an appreciable gain in the size of controlling apparatus, especially on large auxiliaries, so that, aside from the slight objection, perhaps, to the use of as high voltage as this on the ship, the advantage seems to be on the side of the higher voltage.

As to the question of the banishment of the slate, it seems to me that has been a very good move, because all of us had considerable trouble with slate from breakage. When the company with which I am associated went to the Navy Department a few years ago and asked permission to supply asbestos switchboard panels, etc., on battleships, they gave consent very reluctantly, at our risk entirely. They now specify the asbestos material, which shows quite a change in opinion.

As regards electric steering gear, the chief advantages inherent in this type of apparatus were outlined pretty fully in my paper* presented at the May meeting in New York; it is not necessary to go into that further. I should like to ask Mr. Day if I correctly understood him to say that the decision as to the use of the contactor system on these ships was based on the ground of horse power only. Did that decide the matter?

***Electricity the Future Power for Steering Vessels*, this volume, p. 619, Part I.

Mr. Hornor brought up the question of whether or not it is of any real advantage to electrify the anchor windlass, and said that the principal advantage is in doing away with the steam pipes. That probably is the greatest advantage, doing away with the condensation of steam in those pipes and the weight of the piping, and also there is some saving in weight of the auxiliary itself. Further, an electric motor is a better machine than a steam engine, and you can put in more power in the same space than you can with a steam engine. The steam engine has to be designed for maximum torque, and sufficient strength to develop that torque, while in the motor you have an overload capacity available that does not compare with the condition in the steam engine. Mr. Hornor said that the anchor windlass on the *Moreno* had one-half the horse power of the steam engine equipment. That is probably a misunderstanding. I should like to ask him what is probably the horse power of the steam engine equipment.

One of the speakers made a reference to a dynamic brake in Fig. 16, which I should like to correct. The brake in the figure is a motor disk brake, on which point Mr. Day will bear me out. I assume there is a dynamic brake in the equipment also.

With Mr. Pierce, I think that Mr. Hornor's statement in his last paragraph ought not to go entirely unquestioned, to the effect that the installation of a number of the auxiliaries is a new departure from American practise, particularly in the United States Navy. As Mr. Pierce has said, on the Russian battleship constructed in Philadelphia before the *Moreno* was projected, most of these auxiliaries were installed. Also, the United States Navy at the time that this battleship was first started certainly had under test electric steering gears and had under consideration electric anchor windlasses, and long before the *Moreno* was constructed our navy had installations of both.

B. B. Bierer: There are a few things that I understood Mr. Pierce to say that have made me wish to make a few suggestions to those who are interested in the subject. One was the statement that there is no more use for two dynamo rooms on board a ship than there is for two engine rooms. That is correct, possibly, but I think there are, as a rule, two engine rooms on battleships, and sometimes three. We have tried the one dynamo room proposition and we have gone to two dynamo rooms or possibly an additional room for a Diesel engine above water for wireless, in case the dynamo rooms are submerged. We wish to take every precaution against placing the ship entirely out of commission. Of course the motive power might be placed out of commission with either one or two engine rooms, but that would still leave fighting power, provided we had a dynamo room in commission, as that is entirely electrically controlled—that is, lighting and fighting power and the wireless—and it would be a pretty dangerous proposition, even with the motive power out of commission, for someone else of at least smaller fighting power to come too near. In addition to the use of the wireless and power—which is electrical power, the fighting power of the ship—of course you can see very readily the advantages of having a number of means by which a ship cannot be put entirely out of commission.

I was very much interested in the remarks Mr. Pierce made in reference to the question of conduit or armored cable, because I have been associated with the use of conduit for a great many years, and the advantages that were claimed in the adoption of conduit have not been secured in the Navy, although we stuck to it for many years. One is water-tightness. That was impossible. The conduit installation was supposed to be water-tight, both in itself and where it passed through water-tight bulkheads, but in collisions that have occurred, when the compartment in collision was shut off and pumped out to put a patch on, water simply poured into the compartment and it was found it came through the conduit—simply had leaked in in streams. Now in addition to this leaking in in streams, when the decks are washed down and various things of that kind done, moisture gets into the conduit. It accumulates a mass of muck and corruption there at the end of a few years, everywhere the moisture gets in, and it is almost impossible to keep it out anywhere, any time or any place. That breaks down the insulation and one pretty soon finds so many grounds in the electrical installation of the ship, that were the ship to be used as a fighting machine and require all her electrical power, she would be absolutely unable to come up to the requirements.

Armored cable absolutely does away with grounds in the cable itself. Of course, there may be grounds in the junction boxes, connection boxes, and fixtures, but as far as the cable is concerned, unless that is pierced there are no grounds possible. The lead around the fiber insulation of the wire itself makes a perfectly water-tight seal. Then the mechanical protection—the wire braid—is very strong. You can bend that. You can put the end of the cable in a vise and bend it back and forth "until the cows come home," as they say, and it is still as good as ever, and the lead itself will break before the wire braid will.

Now as to the question of induction. We formerly used a great deal of what we call open work wiring instead of the conduit, to lessen weight and lessen this mass of pipes running around and underneath the beams—dust collectors and vermin collectors and having a most unsightly appearance. The question of induction, and wireless and other electric currents from one cable to another, was such that a short time—I don't mean to say a short space of time necessarily, but a short time in the life of a battleship—two or three years—would put the electrical installation out of commission as far as grounds are concerned. It had to be all gone over again every year. Where there is any trouble in conduit installation, it means tearing out the whole thing and putting in new. These are points in the consideration of conduit and wiring that come up from experience and are absolutely necessary to consider.

We do not have that small kuhlo (concentric) wire in use in our service, but it looks very good to me. It is neat, though a little expensive, and it certainly would be extremely desirable from a naval viewpoint.

J. H. Linnard: The great difficulty with the application of electricity to the windlass engine is the fact that the normal condition of a windlass when it is being operated is to be stalled, and you never know when that is going to happen. It stops at the most unexpected times. Now the question is, if you get the armature of your motor working at a speed that gives very considerable inertia forces, how are you going to deal with that when the unexpected jam occurs, as it practically always does occur, when the anchors are being weighed? I haven't heard how that matter has been dealt with in these recent electrical installations for windlass engines, so that I do not feel able to speak about the matter.

I am glad to hear Commander Bierer tell us that conduit has been abolished in the later ships of the Navy, because from the point of view of a naval constructor it was precisely those difficulties of the weight and lack of water-tightness of conduit that always caused us to be on our knees to the Electrical Department to abolish it, but at that time they saw so many advantages in the use of conduit that they were unwilling to do so.

W. F. Cochrane: I appreciate the opportunity to join in the discussion of this paper, remarkable for its completeness, before this society that has done more to enlarge the field of electricity than any other organization in this or any other country. In fact, I think I may say that a great deal of the electrical supremacy of the American manufacturer is due to this Institute through its meetings and its frank and open criticisms.

Any criticism I may make of the paper that has just been read will be from the battle point of view and from that of experience in the practical handling of electrical installations on board ship, and not from the standpoint of an expert electrician, as my electrical knowledge is limited to the practical handling of electrical installations on board ship.

The keynote of any installation for a battleship should be simplicity. If possible, only one voltage should be used on the entire ship for all purposes. The number of feeders should be reduced to a minimum and all efforts should be turned towards the one great objective of making the installation as simple as possible. The character of electricians available makes this element of simplicity imperative. The United States Navy has been rightly named "a great educational institution." The electricians that we have in the navy are men who enlist and have a small amount of experience and knowledge in electricity. These men are then sent to an electrical school where they receive instruction in the various appliances used on board ship. The period of time occupied by this is about one year; the man is then sent to some ship in an inferior position as an electrician. From this you can easily see how important the item of simplicity becomes in the design of the electrical installation of a battleship.

In the installation just described, I do not consider that simplicity has been attained to the extent that it could have been. First, in the use of 230 volts, for which a saving is claimed, but which we may seriously doubt, due to the installation of transformers to enable the searchlight system to be operated at the most advantageous voltage. I am not in favor of the use of high voltages on board ship unless a great saving in either weight or cost, or a simplification of the systems, will result therefrom. One disadvantage is that the use of higher voltage leads to considerably great liability to insulation troubles.

The installation of great numbers of protective devices, in my opinion, serves no useful purpose. There should not be any necessity for a protective device such as a circuit breaker, except at the switchboard. The line itself should require no protection. A fuse at the particular piece of apparatus on the line, whether it be a motor, indicator or any electrical instrument, should be ample protection for this installation.

In the matter of lighting circuits, we have, in the installation described, two battle lighting circuits, one white and one blue. I personally am not in favor of more than one battle lighting circuit, although the blue light circuit has its advantage in the fact that blue lights can be used in the gun deck compartments and will show very little light outside, but there should not be any necessity for general lighting around the compartment of a broadside gun. In turrets and in enclosed places, white lights are used as they cannot be seen from the outside. The greatest protection a battleship can have against submarines and destroyers operating at night is absolute darkness. The blue light circuit may not give much light, but it will certainly be easier to discover a battleship with a blue light circuit lighted than one with absolutely no light showing.

In regard to the battle lighting and power circuits of a battleship, I am heartily in favor of the use of alkaline storage batteries for the battle service. I believe that this is the best solution of the many problems confronting the designer of an electrical installation on board a battleship, because the storage battery can be installed in the turret to operate everything in the turret, and then the only possible way to affect the power units of the turret would be to put the turret itself out of commission.

In regard to interior communications, battle lighting, it is much better if operated by a storage battery which can be placed in such a position that before it is injured or any of the leads are injured, the ship itself will be practically destroyed insofar as she is valuable as a fighting unit. We may also say that an installation of this kind will save considerable space and some weight, as it will do away with the requirement of two dynamo rooms and it will be possible to place the dynamo room as an auxiliary to the engine room, or combine the two into one power plant, in case electric propulsion is adopted for battleships, as most of us believe it will be in the near future. It will combine the dynamo room and engine room in one locality that can be protected to such an extent that it will be practically impossible to injure the installation in any way.

The design of interior and exterior means of communication on a battleship is subject to practically constant change, and it is believed that these systems will be radically changed in the near future, with the advent of an invention to indicate automatically, in any part of the vessel, the color of smoke emitted from the stack, and with the application of the principles involved in this invention to general methods of interior communication in time of battle.

To sum up, the electrical equipment of the Argentine battleship *Moreno* is the most complete that I have ever seen, although I doubt the battle usefulness of a great many features that have been installed on board. I think it would be far more creditable if the designer had been able to say, "we have an installation that will produce the same results as the installation that was placed in the last battleship built, and we have only used half the miles of wire and half the fixtures and we only have half the number of protective devices and half the number of automatic starters and auxiliary instruments."

Clyde S. McDowell: Mr. Hornor described a method of telling the trueness of the searchlight mirror which is known as the "screen test;" it is done by photographing a reflected image of parallel wires or lines. However, this only shows the trueness of the grinding, and is not an indication of whether or not the mirror is parabolic. In addition to testing for trueness of grinding the mirrors should be tested for over-all efficiency. This can be done by taking a mirror and placing at the focus a concentrated-filament tungsten lamp or other source of light, and, at a distance far enough away so that the light varies inversely as the square of the distance, measuring by photometer across the beam in both directions the actual light received on the distant screen. In this method the source of light is known and always the same, and a true indication of the value of the mirror is obtained. It has been found by tests that one mirror which showed by the screen test to be perfectly true in its grinding, put up against another mirror which showed marked irregularities in grinding, did not show as good results in actual illumination, due undoubtedly to the structure of the glass, the thickness of the glass, or the color of the glass.

There was a question brought up as to the 220- and 110-volt systems on board ship for lighting. We have made numerous tests on vibrating platforms and lamps in both horizontal and vertical position, both 220- and 110-volt lamps—these platforms vibrating at the regular period of vibration of a ship—and in the sizes of higher wattage we find that the 220-volt lamps have as long life as the 110-volt lamps. That test is made with the lights on half the time and off half the time, so that the regular service conditions are obtained.

On the question of using a balancer set for searchlights on 220 volts, that is probably a good engineering way to cover it, but on some of our larger ships we are using 220 volts and have a balancer set to take the unbalanced lighting load large enough to take in addition the unbalanced load of four searchlights, which would be putting the searchlights on the lighting circuit.

On the question of doing away with conduit, one of the reasons why conduit has proved unsuccessful on board ship, especially in the fire rooms and engine rooms, has been the condensation in the conduit, irrespective of whether it was water-tight or not. The great changes in temperature that take place, cause the conduit to fill up with water.

Maxwell W. Day: A remark was made about the desirability of having the dynamo plant independent of the propelling machinery. This has just been illustrated in a recent naval battle, where the steam pipe of one of the German destroyers was shot in two, and the boat was seen to be enveloped in a cloud of steam, but frequent puffs of the gun were seen through it. Of course this was not an electrically operated gun, being only 3½ inches, but it showed that the battery could be continued in action after the propelling machinery is out of order. It seems to me that one of the best ways to promote the independence of the dynamo plant is to bring into more extensive use oil-engine-driven sets.

Naval Constructor Linnard spoke of the way of taking care of the anchor windlass in weighing the anchor, where the engine simply would slow down and stop. An ordinary control equipment of electric motors would naturally blow the circuit breaker. As mentioned in Mr. Hornor's paper, a step-back relay is provided, which will open some of the secondary connections of the accelerating contactors, and reinsert a certain amount of resistance in the armature circuit. This will allow the armature to receive about 1¼ times full-load current, or, of course, it can be adjusted for any other desired value. This was tested on the *Rivadavia* by setting the brake on the wildcat and screwing it down until it became sufficient to trip this step-back relay, when the motor stopped, and the current amounted to about 25 per cent overload.

Mr. Hibbard asked if we determined our recommendation for contactors solely on the horse power. It is primarily on current capacity, which would be also according to horse power, assuming voltage unchanged, and we have felt that in very large sizes frequent operation of the contactors successfully is quite a serious problem, and therefore we recommend the variable-voltage system for large units; but with only 150 h.p., and where 220 volts is used, as here, it brings it within the class of moderate-sized equipments.

Mention has been made of the disk brake on the steering gear motor, shown in Fig. 16. This brake is quite small, because we depend principally on the dynamic brake itself to stop the armature, or begin the stopping of it. The disk brake, which is a little slower in action, finishes the work, and holds the armature in a state of rest.

In regard to the material for switchboard and control panels, what is used for this purpose is ebony asbestos wood, called by some, asbestos lumber impregnated. It takes a fine polish, has very much the appearance of slate, and is preferable, I think, to what ordinarily goes by the name of asbestos lumber.

L. C. Porter: The chief difficulty in making 220-volt tungsten lamps is with the arcing. Where the leading-in wires come out of the stem, the current is apt to jump across. Considerable improvement has been made in this respect since the first lamps were put out, but at present the 220-volt lamps are not so free from arcs as the 110-volt, though the percentage of arcs is relatively small. Another difficulty encountered with the 220-volt lamp is what we call " locking " of the filaments. This consists of the filaments jarring together and short-circuiting a section, thus considerably shortening the life of the lamp.

The efficiency of the 220-volt lamp is also somewhat lower than that of the corresponding 110-volt lamp. For example, the 25-watt 110-volt lamp operates at 1.05 watts per candle; while the 25-watt 220-volt lamp operates at 1.2 watts per candle.

There are two types of filament construction used in the 220-volt lamps. In the regular pear-shaped bulb, with which you are all familiar, we use simply a straight wire filament. That filament is shaped on a form before it is placed in the lamp. It is also mounted on flexible anchors, which make the lamp mechanically just as strong as the 110-volt lamp. In the round bulb, and in the tubular bulb, in order to get the filament in the small bulb, we have to wind the filament into a helix and then mount it, which again lowers the efficiency of the lamp by cooling the filament at the anchors. In these lamps 1.06 watts per candle is the lowest specific consumption that we are able to obtain. Life tests on the 220-volt lamps of 25-, 40- or 60-watt sizes, under laboratory conditions, have shown that we obtain 2000 hours' life out of the straight filament and from 1200 to 1800 out of the coiled filament.

The tests which we have made on the lamps at the laboratory consist of vibration tests and bumper tests. The bumper test is made in this manner: We have an inclined board, at the end of which a lamp is hung on a piece of lamp cord. The board is graduated in inches and a round ball, weighing 110 grams, is rolled down this board, which has an elevation of 11½ deg. The ball is allowed to bump against the lamps, both cold and burning. Of course, lamps when burning are not quite so brittle as when cold, because the filament is softer when it is hot. Often with the lamps burning we can roll this ball from 40 to 60 in. against the lamp before the filament breaks, and that is just as far as we are able to roll it with the 110-volt lamps. In other words, the filament is mechanically as strong as the 110-volt lamp filament.

The vibration test is made upon a wheel with arms on it (similar to the spokes of a wheel), and the lamps are mounted at the ends of the arms. There is a series of cogs over which these arms pass. This wheel is revolved over the cogs at various speeds, with a little spring under each arm to pull it down, giving it a very severe vibration; in fact, we can get almost any vibration that we want. On that wheel I have seen as severe a vibration as is obtained on battleships under operating conditions. I have been aboard some of the ships during target practise, full-power run and a few other severe trials, and feel that in this test we give the lamps just as severe treatment as they obtain on the ships in actual service. However, as I stated before, the trouble is not mechanical breakage, but locking of the filaments, which shortens the life.

It seems to me, therefore, that if there is a decided call for the 220-volt lamps, there need be no hesitation in installing them on the ships. Of course, it is a harder lamp to make, is more expensive, and is not made in such large quantities as the 110-volt lamps. For these reasons, from the lamp manufacturer's standpoint, we should prefer to furnish the 110-volt lamp, because it is a lamp with which we have had a great deal of experience. We have not had the 220-volt lamps under service conditions in any great numbers, and before being absolutely sure that they will be satisfactory, the most I can say is that we would suggest that, if possible, the same arrangement be made as was made with the 110-volt lamps; namely, that about 2000 lamps be put on a ship and tested in service. This, it seems to me, is the only sure trial which will absolutely prove the merit of the 220-volt lamp.

H. A. Hornor: I should like to explain an evident misinterpretation of the last paragraph of my paper. The various applications therein referred to constituted departures from American practise at the time the contract for the *Moreno* was signed. Many of these applications were in an experimental stage at that time, and during the five years of construction of the *Moreno* naturally these applications have become requirements. As an illustration of this, the United States battleships *Arkansas* and *Wyoming* were not equipped with electric bilge pumps, electric steering gear, and electric anchor windlass; whereas the United States battleships *Texas* and *New York* were equipped with electric steering and electric bilge pumps but not electric anchor windlass. The later United States battleships are to be equipped with all these outfits. I did not intend my remarks to convey the impression that I was comparing previous foreign war vessels built in this country.

The horse power of the electric anchor windlass on the *Moreno* is a little less than ⅓ the horse power required of the steam equipment. It is to be noted that one anchor was raised in about 60 fathoms of water by this equipment using about 35 horse power after the anchor had " broken away."

I believe that there are many advantages in the use of 230 volts for such installations. I have heard it stated that some nations were considering the advisability of increasing the voltage to 500. If proper insulation is provided and all questions of detail carefully looked after, I see no reason why 230 volts should give any more trouble than the present 125-volt system. In this connection I was glad to hear the remarks on the comparative merits of the 220-volt tungsten lamp. On the ground of simplicity of installation, the use of this voltage would be preferable to the complications that would ensue from a system of double voltages. In view of the fact that the power load is now by far the greatest in point of importance it would seem preferable to design the installation so as to satisfy this demand first. The searchlights could very well be taken care of by rotary balancer sets in order to do away with the difficulties involved in large permanent rheostats. Such apparatus when tested on the *Moreno* gave unqualified satisfaction.

Presented at the 300th meeting of the American Institute of Electrical Engineers, Philadelphia, Pa., October 12, 1914.

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ELECTRICAL FEATURES OF THE U. S. RECLAMATION SERVICE

BY F. H. NEWELL

ABSTRACT OF PAPER

The operations of the U. S. Reclamation Service are of interest to electrical engineers not only in some of the novel developments and applications of power but also as illustrating the efforts of the federal government in the construction of works of general public utility.

One of the most interesting features is the question of cost of government work, much of which in this case is executed under pioneer conditions. These costs are carefully recorded and include all of the overhead or general expenses. These costs show that during 1913, for the various plants there was a range from 0.68 cent per kelvin or kw-hr. up to 2.873 cents. The power not needed for construction purposes or for operating irrigation works is being sold at rates of 1.5 cents per kw-hr., and for excess power as low as 0.5 cent, up to 2 cents or over. For heating the rate charged per month from June 1 to September 1 per device per 1000 watts is $1.50.

The experience obtained is illustrating the fact that it is practicable for the government to build and operate plants of this kind and sell the power at cost, in connection with other enterprises and with general satisfaction to the consumer. The power plants will be paid for without profit or interest and the operations transferred as soon as practicable to the communities benefited by them.

THE electrical engineer as a professional man finds much of interest in the works executed by the United States Reclamation Service and in the plans under consideration for further enterprises. Electrical development and transmission enter largely, not only into the construction, but also into the operation of the works for the irrigation of arid lands, which are being built under the terms of the act of June 17, 1902. This act sets aside the proceeds from the disposal of public lands in the western arid and semi-arid states, for the purpose of survey, construction, operation, and maintenance of works for the storage and distribution of water for irrigation and reclamation of arid lands.

Aside from his purely professional interest, the electrical engineer, as a citizen, is concerned in all of these matters which have to do with the upbuilding of the United States, the utilization of its natural resources, and the increase of the prosperity and happiness of the commonwealth. Both of these phases, that of interest to the professional man and to the citizen, are briefly discussed in the following paragraphs, the attempt being made to describe in a concise way the works which have been or are being built and to give the relationship of these to the larger economic or political problems of the country.

Object. The main purpose in the development of electric energy by the Reclamation Service is the production of cheap power for raising underground water to the surface or surface waters to lands which are too high to be reached by the ordinary gravity method throughout. There are other uses, however, to which this energy can be economically applied. Taking these in the sequence of events they may be summed up as follows:

1. *Transportation.* This includes the building and operation of works for transporting material to be used in construction.

2. *Construction.* This embraces all electrical devices employed in the handling of materials, in lighting the works and in facilitating other operations.

3. *Pumping.* As previously stated, this is the most important use of the electric energy which is developed in the course of the work of the Reclamation Service.

4. *Commercial.* An important outgrowth of the above is the disposal of excess electric energy developed largely in connection with pumping, but sold for lighting or industrial purposes, proceeds being used to assist in defraying the cost of the pumping of water for agricultural purposes.

Methods. The methods of development of electrical energy and the character of machinery employed are largely those of the usual commercial practise, the attempt being made to keep well in the lead. In some cases, notable advances have been made over customary methods. As might be inferred, the largest amount of energy is developed by the use of water power. In other words, hydroelectric planning and construction form the principal feature of this class of engineering works. There are, however, a number of relatively small plants in which the energy is derived from the consumption of fuel either utilized in the production of steam or in the more direct use of oil or gas in the ordinary engines developed for this purpose.

Costs. In all of this work undertaken by the Reclamation Service, not only in connection with electrical development and use, but also in its other operations, careful records are maintained of the actual cost of the various items. Quite frequently in statements of cost prepared by other bureaus of the government, the matter of overhead charges has been neglected or many items which are properly to be considered in this connection are not entered because they are carried on regular appropriations. These neglected items usually consist of salaries of permanent officials whose time is largely devoted to the particular work in hand but is not charged to it. For this reason, the costs prepared by the Reclamation Service give, perhaps, a more accurate conception of actual and necessary expenditures than those usually obtainable from records kept by government bureaus.

Without entering into an elaborate discussion of these costs, it may be said that they range, in general, from a few mills, or even less, per kilowatt-hour for power developed in large quantities by hydroelectric plants, up to a few cents per kilowatt-hour as developed by steam plants.

The costs for 1913 are shown in the following table:

POWER PLANTS OPERATED BY RECLAMATION SERVICE IN 1913.

Reclamation project	Power plant	Location	Type	Capacity kw.	Annual load factor, per cent	Output in kw-hr.	Cost in cents per kw-hr.-(a)
Salt River.....	Three plants	Arizona	Hydroelectric	8,500	12.7	9,518,570	0.810
Boise.........	Boise	Boise R. Idaho	"	1,875	43.2	7,092,123	0.208
Minidoka	Minidoka	Snake R. Idaho	"	7,000	40.1	28,205,287	0.120
Truckee-Carson	Lahontan	Lahontan Nevada	"	1,250	8.5	930,300	1.118
Rio Grande....	Elephant Butte	Elephant Butte Dam New Mex.	Steam turbine elec.	1,875	12.6	2,065,840	2.873
No. Dakota Pumping......	Williston	Near Williston N.D.	"	1,150	11.4	1,146,337	2.014
Strawberry Valley..........	Spanish Fork	Near Sp. Fork, Utah	Hydroelec.	850	11.0	801,705	2.072(b)

(a) These costs are at power plant switchboards and include in addition to all maintenance and operating expenses, general expense and plant depreciation.

(b) Includes heavy canal expense.

For purposes of comparison with the above statements of cost, it may be said that it is a popular belief that the cost of manufacturing electric power at Niagara Falls is about 0.2 cent per kilowatt-hour, and that for power development in blocks of say 5000 kilowatts and upward, it is more economical to erect a modern steam power plant at Buffalo than it is to transmit this energy from Niagara Falls at a cost at Buffalo of say 2½ mills per kilowatt-hour. In other words, the modern economy of the steam engine and generator is such that when fuel is cheap, current can be manufactured on the ground and utilized without transformation more economically than it can be transformed and transmitted over a considerable distance. The cheapest hydroelectric power reported is in the South, stated at 0.1 cent per kilowatt-hour, or about $6 per h.p. per year.

On the Minidoka Project of the Reclamation Service, the cost of producing power at the plant switchboard is seen from the above table to be about 1¼ mills. The surplus power over that needed for irrigation pumping on this project is sold as a by-product. For this purpose the Reclamation Service contracts with a local company or distributor, protecting the ultimate consumer by provisions in the contract limiting the maximum rates chargeable by the distributor. These rates are shown in the table on the following page.

Fallacies. In developing hydroelectric power for irrigation pumping, it has been necessary to meet many popular fallacies concerning the cheapness of water power. It is generally assumed that because the water is flowing more or less continuously throughout the year, making possible a large amount of power, that therefore, the power itself must necessarily be cheap. Little consideration is given to the large first cost of installation, of development of the power, to the interest on the investment and particularly to the depreciation.

Few people outside of the profession of electrical engineering understand that the utilization of the natural water power is accompanied by heavy expense, notably in fixed charges for interest and depreciation, and that these may far exceed the more obvious costs of a steam plant. Obsolescence also must be considered, especially in waterwheel development. Great improvements have been made along that line, so important that no up-to-date power plant manager can ignore taking advantage of them. While in purely electrical apparatus obsolescence is becoming less and less of a large factor, if the plant is properly designed, yet it must be considered. The heavy item and one not usually appreciated is, as above stated, the interest, depreciation and other fixed charges inseparable from a large capital investment. It is not an uncommon thing for a unit of hydroelectric power generation transmission and transformation at the substation to run into $250 to $300 per kw., while a steam plant in large sizes may not exceed $45 to $60, or at the most $75 per kw. On the other hand, the depreciation of a steam plant and repairs of the same are much in excess of the hydroelectric system as a whole, but this does not modify the fact that it is often cheaper to build steam plants to meet load conditions rather than to furnish it by hydroelectric power. This, as above stated, it is difficult to bring to public comprehen-

IDAHO—MINIDOKA PROJECT.
Electric Power for Commercial Use.
(Contracts Nos. 322, 323 & 326 and supplemental contracts.)

Monthly Rates.			
To distributor		To consumer	
Per incandescent light of 15 watts.....	$0.03	For 20 incandescent, 15 watts ..... 5c, each additional light	$1.50
Per incandescent light of 15-60 watts...	0.10	For 5 incandescent, 15-60 watts.... 25 c. each additional light	1.50
Per incandescent light over 60 watts... for each 60 watts or frac.	0.10	Per light over 60 watts, for each 60 watts or frac..................	0.25
Per arc light, 700 watts to 10 p. m......	1.50	Per arc, 700 watts to 10 p. m.........	2.50
Per arc light, 700 watts all night.......	2.50	“ “ “ “ all night.........	4.00
Heating Rates.			
Per device, Sept. 1—June 1...........	$0.50	Per device 1000 watts Sept. 1-June1	$1.00
Per device per 1000 watts June 1—Sept. 1,...................	1.50	Per device per 1000 watts June 1—Sept. 1,..............	2.50
Flat-Iron Rates			
Per flat-iron 700 watts...............	$0.25	Per flat-iron 700 watts.............	$0.50
Metered light and appliance rates, per kw-hr.			
First 2500 kw-hr. in mo...............	$0.027	First 25 kw-hr. in mo.....	0.07
For 2,500-5,000 kw-hr. in mo.........	0.025	For 25-50 kw-hr. in mo	0.06½
For 5,000-10,000 “ “ “	0.023	For 50-100 “ “ “...........	0.06
In excess of 10,000 “ “ “	0.021	In excess of 100 “ “...........	0.05½
Power Rates, per kw-hr.			
First 2,000 kw-hr. in mo.............	$0.01	First 100 kw-hr. in mo............	$0.05
For 2,000- 3,000 (do)	0.007	For 100-200 (do)...........	0.04
For 3,000- 5,000 “	0.0055	“ 200-500 “	0.03
		“ 500-1000 “	0.015
For 5,000-10,000 “	0.0053	“ 1000-2000 “...........	0.008
		“ 2000-5000 “	0.007
For 10,000-25,000 “	0.0051	“ 5000-50000 “	0.0063
		“ 50000-75000 “	0.0060
In excess of 25,000 “	0.0050	“ 75000-100000 “	0.0057
		In excess of 100000 “	0.0055

sion, namely, that electric power developed from water power is sometimes more expensive than the equivalent amount of power developed, when needed, by economically operated steam or gas engines.

One of the popular misapprehensions which has given rise to considerable disappointment to the settlers on government projects is the lack of appreciation of the fact that electric energy after being developed must be raised to high voltage for long distance transmission and again transformed before distributing to the consumer and that such transforming apparatus is quite expensive.

The farmer, seeing a high-tension line skirting his farm, cannot readily be made to understand why he cannot purchase a small amount of electricity for use on his farm or in his house. It is necessary to explain to him that the difference is almost as great as would be in a case where he might argue that because a tree grows on his land, he should be able to get his tables and chairs at relatively small cost! The transformation of a tree into a chair may be as difficult as the transformation of the high-tension electricity into a form such that he can safely use it around his house or barn.

There has also been an exaggeration in the minds of the people in the communities on some of the government projects of the importance to them of the power plants which have been built in connection with the pumping and related work. They seem to think that these are an asset which they can utilize for more or less speculative purposes and that the earnings of these power plants will notably reduce the cost of the irrigation works and possibly save the water users from any expenditure. They have an exaggerated idea of the earning power of these works, not appreciating that many of them can be operated only during the irrigation season, and that electric power developed under these circumstances has small commercial value. They have heard of the great earnings of the water power monopolies and picture to themselves the advantages of securing a monopoly of this kind which they can handle to their own immediate profit, forgetting that the manufacture and sale of electricity developed by water power is a highly specialized business, like the manufacture of any other commodity, and one which is not always financially successful, and then only because handled by men of exceptional ability.

Uses. As above stated, many of the uses for electric power developed by the Reclamation Service are those in connection with transportation of materials and construction of works. There is not much of novelty to be considered in this connection, as the devices employed are usually standard in design. They consist of light electric railroads, such as are needed in construction of tunnels and in similar work, and apparatus for the operation of cement plants, cableways, hoists, excavating machinery, etc., lighting plants being, of course, an important adjunct.

Pumping, however, forms the great and principal use of the electric power development and there were installed 9235 h.p. in permanent pumping plants used in 1913, in addition to numerous small drainage installations, semi-portable and intermittently used. The cost, including all overhead charges and depreciation, has been estimated to average about one cent per acre-foot raised one foot, ranging from 0.3 cent per acre-foot at Minidoka, upward. That is to say, an amount of water covering an acre one foot in depth, or 43,560 cubic feet, can be raised to a height of 50 feet for fifty cents.

In comparison with this, water raised by the ordinary small steam or gasoline pumping plant built by associations of farmers throughout the arid regions is probably costing from 7 to 10 cents per acre-foot raised one foot, including, as above stated, interest and depreciation. With better and more economical devices for raising larger quantities the cost may be cut down to five cents, or even, under exceptional conditions, as low as three cents, while those of the government works, as above stated, may run as low as at Minikoda in 1913 when it averaged 0.346 cent.

Sales. Sales of power for commercial and other purposes are made at varying rates, dependent mainly upon the cost of development. As a rule, the electric energy is sold by the government as nearly as possible at cost. The reason that the cost varies so widely is due primarily to the difference in conditions of development, and, secondarily, to the conditions attached to the sale, particularly as to the continuity of demand by the consumer.

The ordinary price or what may be considered as a standard of the Reclamation Service for current for commercial purposes in large lots is about 1.5 cents per kw-hr. Under extraordinary conditions where excess power is sold whenever developed and is used as an auxiliary for steam power, the price has been as low as 0.75 cent per kw-hr. or even 0.5 cent.

In one case in Utah the Reclamation Service is selling at 0.8 cent per kw-hr., with a guaranteed minimum charge of $225 per calendar month. While this is a comparatively low rate, it is not as low as the minimum rate given the Reclamation Service in purchasing power in Montana, where a company has built a considerable amount of transmission lines in order to secure the business of the Reclamation Service in the construction of the Sun River project.

The essential feature in these extraordinary low prices is that the Reclamation Service is selling surplus power and that there are two unusual clauses relieving the United States from obligation to furnish power in case it should become inconvenient to do so, as follows:

"The United States shall have the right and privilege to shut down its power plant and cease serving electric energy at any time in order to make necessary repairs or additions to transmission lines, canals, or machinery."

Also it is stated that "in case of the shortage of power due to lack of water, or if the demand for power for construction purposes causes the furnishing of power to the city to impede the progress of construction work on the project, the United States reserves the right and privilege to cut off the power until such time as it is possible to furnish power without impeding the progress of construction work."

The rates charged for heating and similar purposes vary widely, as above noted, dependent upon there being an excess of energy during the winter season when water is not pumped for irrigation. Not being sold or disposed of for profit, the rates for sale approximate usually, as above stated, nearly the actual cost, these being so low in some cases as to compete with coal at $7 per ton in heating houses and in cooking.

Power Development. The following figures give in concise form and in alphabetic order by states the power already developed, together with the total proposed or possible power and the output. Following the tables there is also given a brief description of some of the more important power plants with their chief characteristics. The most notable of these is on the Salt River project in Arizona, the principal power plant being located at Roosevelt dam and the subsidiary power plants along the canals which are supplied with water largely from the reservoir created by this dam.

POWER DEVELOPMENT* (Water Power unless Otherwise Specified).

Project.	Name of Plant.	Maximum head (feet)	Horse power	
			Prime-movers installed	Total† proposed or possible
ARIZONA:				
Salt River...........	Roosevelt (a)	226	8,640	15,640
" "	So. Consolidated (b)	30	2,800	2,800
" "	Arizona Falls (c)	18	1,450	1,450
" "	Crosscut (d)	117	6,000	6,000
ARIZONA-CAL.:				
Yuma	Drop in Cal. Canal	9		1,000
"	Araz	25		7,700
CALIFORNIA:				
Orland..............		27		483
COLORADO:				
Grand Valley	Main Canal	44		3,600
Uncompahgre........				10,000
IDAHO:				
Boise...............	Boise Dam (e)	30	2,550	2,550
"	Arrowrock Dam	230		17,000
"	Drops in canals	20-90		4,800
Minidoka...........	Minidoka Dam (f)	50	10,000	20,000
KANSAS:				
Garden City.........	Deerfield (steam) (g)		700	700
MONTANA:				
Flathead............	Flathead River	60		360,000
"	Revais Creek	1000		26,000
Huntley.............	Main Canal drop (h)	34	286	600
MONTANA, N. D.:				
Lower Yellowstone ...	Lateral K. K. drop			290
NEVADA:				
Truckee-Carson......	Lahontan ( )	120	1,800	6,000
" "	26-foot drop	26		2,000
NEW MEXICO-TEXAS:				
Rio Grande..........	Elephant Butte (steam) (j)		2,000	2,000
" "	" " (hydroelec)			10,000
NORTH DAKOTA:				
N. D. Pumping	Williston (steam) (k)		1,550	1,550
OREGON:				
Klamath............	Various sites	22-88		9,700
Umatilla............	Drainage outfall	28		145
UTAH:				
Strawberry Valley....	Spanish Fork (l)	125	1,600	3,500
WASHINGTON:				
Yakima, ...				
Sunnyside Unit	Drops in canals	20-88		1,800
Tieton Unit.......				3,250
Wapato Unit				9,000
Okanogan...........	Drop No. 1 (m)	105		250
"	" (n)	56		300
"	Salmon Creek	441		2,800
			39,376	632,908

*Power may be developed on other projects, but data not completed.

†Turbine capacity.

(a) Three 1680-h.p. and two 1800-h.p. turbines; five 1060-kw. generators.

(b) Two 1400-h.p. turbines direct connected; two 1000-kw. generators.

(c) Two 725 h.p. turbines direct connected; two 525-kw. generators.

(d) Six 1000-h.p. vertical tangential wheels; six 875-kw. generators.

(e) Three 850-h. p. turbines, direct connected; three 625-kw. generators.

(f) Five 2000-h. p. turbines, direct connected to five 1400-kw. generators.

(g) Two 350-h. p. steam turbines and two 225-kw. generators.

(h) Two vertical turbines, direct connected to two 20-inch centrifugal pumps, capacity 28 second-feet.

(i) Two 900-h. p. turbines direct connected to two 625-kw. generators.

(j) Three 625-kw. steam turbine units.

(k) Two 300-kw. and one 500-kw. steam turbine units.

(l) Two horizontal 800-h. p. turbines and two 500-kw. generators.

(m) One 250-h. p. turbine; one 187-kw. generator.

(n) 300-h. p. turbine; one 187-kw. generator.

Other interesting developments are those in southern Idaho; the larger on Snake River near Minidoka, and the smaller on Boise River near the city of Boise. On several of the other projects, power plants have been constructed or are projected, notably in New Mexico at the large dam being built on the Rio Grande and in Utah on the Strawberry Valley project. In the State of Washington a number of small plants are under construction in connection with pumping extensions of the Yakima and Okanogan projects.

At each of the large storage dams, built by the Reclamation Service, there are opportunities for intermittent power, some of which will undoubtedly be utilized after this country has developed to a higher degree and markets are established.

The following extract from material for the forthcoming 13th Annual Report of the Reclamation Service gives in summarized form the capacity, output and construction costs for each of the more important power plants of the Service.

POWER PLANT DATA.

Project	Name of plant	Capacity kw.		Cost	Output kw-hr.	
		Rated	Safe observed		Sold	Used by Reclamation Service
ARIZONA,						
Salt River....	Roosevelt	5300	6000	*$642,654.23	9,336,802	2,932,230
	South Consolidated	2000	2000	162,123.05		
	Arizona Falls	1050	1000	109,500.73		
	Crosscut†	5250		incomplete		
IDAHO						
Minidoka	Minidoka	7000	7420	433,887.21	7,342,063	19,511,603
Boise........	Boise	1875	2400	168,446.05	2,520,422	4,937,031
NEVADA,						
Truckee-Carson.....	Lahontan	1250	1450	85,437.63	219,544	2,110,127
UTAH,						
Strawberry, Valley	Spanish Fork	1000	1000	55,531.71	687,780	156,674
NEW MEXICO,						
Rio Grande...	Elephant Butte (steam)	1875	1875	136,491.83	14,825	3,275,285
N. DAKOTA						
Williston, ...	Williston (steam)	1150	1550	228,699.39	436,300	550,003
Totals ...		22500	24695	$2,022,771.83	20,567,636	33,841,053

*Exclusive of power canal and diversion dam $1,500,459.01. To the cost of this power plant will be added $83,000 to cover a 5000-kw. unit now being purchased, making a total cost of $725,654.23, and a total rated capacityof 10,300 kw.

†Not included in totals.

Arizona, Salt River Project. The power plants built in connection with the construction of the large Roosevelt dam and at several drops along the canals which distribute the water which has been stored behind the dam are among the most important built by the Reclamation Service. They illustrate the development of this somewhat peculiar type, the operation of which is necessarily made subsidiary or secondary to the use of water for irrigation. Here, however, where water is used throughout the year in irrigation the conditions to be met are less severe than those in Idaho, where the water is only used during the summer months.

*" The government has built the Roosevelt dam in the canyon of Salt River, 78 miles above Phoenix, to store over a million acre-feet of water for irrigation in the valley below. The dam is 280 feet high, affording a high head for a hydroelectric power plant. A plant was built below the dam to take advantage of this opportunity to furnish power for pumping underground water to irrigate additional land beyond the capacity of the gravity water supply. A 10-foot penstock through the dam operates machines under a variable head as the water is drawn out of the reservoir.

" The system also includes a power canal of 225 second-feet capacity and 19 miles long around the reservoir, making it possible to get the full head of the dam with the normal flow of the stream at all times. The power canal was built before the dam to furnish power for the construction of the dam itself, so that part of the original cost of the canal really belongs to the dam. The power house at present contains five machines capable of delivering about 5000 kilowatts, and it is intended to install a large machine this year that will bring the total output up to about 10,000 kilowatts. In the valley, the farmers have assessed themselves for money to build three other power plants in places where there is fall in the canal system, having a total capacity of 8000 kilowatts. When the plants now under way are completed the power system will represent an outlay of approximately $3,500,000, including the cost of the power canal. All of these plants are connected by a distributing system consisting mainly of 168 miles of steel tower, 45,000-volt transmission line and about 40 miles of 10,000-volt distributing line. The

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*Abstract of article on the Salt River Valley power situation prepared by Mr. Wm. F. Cone and printed in the *Reclamation Record* for May, 1914.

surplus power over that required for irrigation is sold and the receipts go to reduce the cost of the project as charged against the land irrigated.

"Substations at Phoenix, Chandler, Glendale, Sacaton and Miami are distributing current for various uses. At Phoenix, all the lighting and electric power in the vicinity is supplied by the Government and is used for lighting the city, operating the street railway, ice plants, alfalfa mills and a cement mill. At Chandler, the power is used almost altogether for pumping. At Glendale, the Government supplies power for lighting the city of Glendale, operates several motors for different purposes and also takes care of a large pumping section just outside the project in what is known as the Marionette district. At Sacaton, power is furnished the Indian reservation for 10 irrigation pumping plants, for domestic water supply, and for lights at the Agency and School. At Miami the Inspiration Consolidated Copper Company is now putting in a large mill for handling low grade copper ore. This mill covers eight acres of land, all under one roof. The company will also operate a smelter, the mine machinery, hoists, lighting systems, compressors, and other devices by means of power from the Government system.

"In addition to the above-mentioned uses, the farmers in one section of the valley are now planning to put in a distributing system of their own, covering about 40 sections of land and bringing the power to their homes for pumping domestic water and doing general work around the farms, such as lighting and cooking."

Idaho, Boise Project. In connection with the construction of the Arrowrock dam, said to be the highest in the world, a power plant has been built on Boise River about 18 miles below the site, power being transmitted to the dam for use in construction. After the dam is built there will probably be installed at the reservoir itself a power plant capable of developing about 5000 h.p., which will be used in connection with the power plant now constructed at the lower point on the Boise River for supplying power for pumping water for irrigation and for commercial purposes.

*Idaho, Minidoka Project.** This is one of the largest and most interesting developments of hydroelectric power made by the

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*See detailed statement by Barry Dibble in *Journal of Electricity, Power, and Gas*, July 11, 1914.

Reclamation Service. The power house is at a dam which was constructed across Snake River for the purpose of diverting water by gravity to 70,000 acres. This dam has a maximum height of 86 feet and a length of 937 feet. In addition there is a concrete spillway about half a mile in length on which the water can be controlled by flashboards, thus adding needed storage. The drainage area above this diversion dam is 22,600 square miles. The normal floods occur in June and usually reach a peak of some 30,000 to 40,000 second-feet. In low-water stage, which follows soon after in July and August, the river drops to 2000 second-feet, although from 2500 to 3000 is a usual minimum.

At all times water must pass this dam, as there are prior water rights to the amount of 3400 second-feet, so that all of the flow up to this amount during the irrigation season must be passed for the use of the lands below if needed by them. This has necessitated the development of storage on the headwaters of Snake River in Wyoming, about 300 miles above the Minidoka dam. This storage is created at Jackson Lake in Wyoming, where by building a low dam an available capacity of 380,000 acre-feet has been obtained, this being in addition to the 53,500 acre-feet which can be held in Lake Walcott immediately above the Minidoka dam and power house.

On the north side of the river, water is diverted by gravity to irrigate about 70,000 acres of land. On the south side, the water diverted by the dam is used mainly to supply lands which lie above the gravity supply and to which the water must be lifted by pumping, utilizing for this purpose the power developed at the dam through the use of the water which must be passed down the river for the lands farther down the stream.

The power is developed under a head of 46 feet and the plant consists of five principal units each having a capacity of 2000 h.p. in the water turbine. These turbines drive electric generators which have a normal capacity of 1200 kw. each and which under a high head have delivered as much as 1600 kw. each.

The storage lake immediately above the dam, known as Lake Walcott, covers 10,000 acres, and is used in summer time as an auxiliary storage in which the water can be raised five feet above the spillway crest of the dam by means of flashboards. When the lake is thus raised additional head is made available at the power house to increase the capacity of the plant. Water is taken from the lake to the turbines through 10-ft. penstocks, each of which carries approximately 500 cu. ft. per second, when operating at full capacity.

Electric energy is generated at 2200 volts, carried by cables through fiber conduits to air-cooled transformers, which raise voltage to 33,000 volts for transmission.

All the wiring and switching beyond the transformers is in duplicate, and all the way through the greatest precautions are taken to prevent any accident. The variation of load on the power house is extreme, the greatest demand being during the heat of the summer when water is needed for irrigation. Great fluctuations are caused by occasional rains which lessen the irrigation demand.

During 1913, the output of the station reached 28,265,287 kw-hr., with an observed peak of 7420 kw., making the annual load factor nearly 40 per cent. The annual cost of operation and maintenance amounted to practically $16,000, or less than 0.07 cent per kw-hr., independent of fixed charges. Including fixed charges, general expense and depreciation, cost in 1913 was 0.126 cent per kw-hr.

From the power house, two transmission lines extend over the project, crossing the river and uniting so as to form a loop over which the current can be supplied. There are about 62 miles of 30,000-volt lines and over 20 miles of 2200-volt lines, supplemented by distribution systems in the towns and owned directly by settlers. The annual cost of operating and maintaining the high-tension lines is about $40 per mile.

The pumping stations which supply water to approximately 48,000 acres of land are the largest which have been built for irrigation purposes. It is believed that the pumping stations for the city of New Orleans which are used in the case of severe rainstorms to remove the storm water from the sewers of the city, are the only pumping stations in the United States which have a larger capacity than those on the Minidoka project. The station buildings, which are of concrete, contain transformers for lowering the voltage from 30,000 to 2200, and also house the motors and pumps.

There are ten pumps which were originally of 125 second-feet capacity, each driven by a 600-h.p. motor, and two 75-second-foot pumps driven by 360-h.p. motors. At each station the lift is approximately 30 ft., so that the lift of the third canal is nearly 90 ft. above the gravity supply.

Approximately 127,000 acre-feet of water were pumped during the season of 1913, and of this, 17 per cent were used on the 30-ft. level, 36 per cent on the 60-ft. level and 47 per cent, or nearly one-half, on the 90-ft. level.

The average lift for the season was 68.3 ft. The power required was nearly 16,000,000 kw-hr. with a peak of 6550 kw., corresponding to a load factor of 27.7 per cent. The cost of operating and maintaining the three stations was $13,000, exclusive of the fixed charge and of the cost of power, or a trifle more than 10 cents per acre lifted the average height. The cost of operation and maintenance of the canal system amounts to an additional 75 cents per acre.

There has been very heavy demand on the pumping stations for a week or ten days in the middle of the summer and at this time all of the machinery has been pushed to its fullest capacity. Efforts are being made, however, to arrange by rotation of delivery of water to spread the demand over a longer period without hardship to the farmers and avoid the excessive demands for the very short period.

During the winter of 1913-14, alterations have been made in the runners of several of the large pumps and recent tests indicate that the changes will increase the capacity from 125 to 165 second-feet and improve the efficiency of the pumps from 72 per cent to over 80 per cent.

North Dakota, Williston Pumping Plant. This plant, although relatively small in size, is of peculiar interest because of the fact that the government owns and operates the coal mines which supply the fuel, this being dug immediately adjacent to the power house, and the coal carried immediately from the mine through crushers into the hoppers which supply the furnaces. Burned there, the steam generated is used in turbines, which in turn convert the energy into electric power, which is transmitted from the power house down to the Mississippi River, is carried out onto barges which contain pumps which in turn lift the water from the river to settling basins on the land, from which it can flow by gravity back to the power house, be there picked up by suitable pumps, raising it about 30 ft., from which level it flows to the lands to be irrigated.

In addition to the power which is used during the summer to pump water for irrigation, there has been provided an all-the-year-round load by making arrangements with the City of Williston for sale of power for lighting the city and for other purposes. It has been found that a government bureau is not the ideal form of organization to handle economically the retailing of electrical power to small consumers. Therefore, the policy has been adopted of aiding the farmers and local people to form mutual companies to build their own lines to connect with the government system, install their own house transformers, and handle the retailing of the power.

Conclusion. In what has been stated above, sufficient detail has been given to illustrate the general character and extent of the works being built by the government through the Reclamation Service and to indicate the policy which up to the present time has been found advantageous. A certain amount of experience has been acquired in this class of development work and the demonstration made that it is possible for the government to build and operate works at a cost comparable to the outlay by ordinary corporations. The results, therefore, have peculiar interest to the citizens of the country as showing what may be done and also the difficulties to be avoided in governmental operations of this kind where the question of profit and interest on the investment is not considered, but rather the general benefit in upbuilding a community under pioneer conditions. When these communities are upon their feet, it is the intent of the law that all of these works be turned over to the landowners and be maintained by them at their own expense, under such regulations as may be desirable at the time. It is to be noted that these landowners are to pay for the actual cost of the work in annual installments which, under the terms of the act of August 13, 1914, have been extended from 10 years to 20 years, without interest on the deferred payments.

The employes of the Government engaged in the construction and operation of these works at all times stand ready to assist the small subsidiary companies or organizations of farmers and water users to build their own lines, to make repairs, and in fact to aid them in every way possible, usually taking the initiative in urging the farmers to find new uses for power. So that ultimately, when the hydroelectric works or big power plants are turned over to the organizations of farmers they will have had experience adequate to operate them through the employment of competent electricians. At present the rural lines cannot be considered a profitable investment from a power company's standpoint. However, they enhance the value of the farms which are reached by the lines and the material saving to the farmers which comes from use of electricity makes the investment a good one from the farmers' standpoint.

DISCUSSION ON "ELECTRICAL FEATURES OF THE UNITED STATES RECLAMATION SERVICE" (NEWELL), PHILADELPHIA, PA., OCTOBER 12, 1914.

Paul Spencer: Upon hearing the paper read, I was struck with the advantages of having someone supply you with money without interest charges, and being able to make contracts on which you could shut off power whenever you did not have it, or did not wish to supply it. Under those circumstances, I can understand that you might be able to sell your surplus electricity at the price stated. The low rates can only be considered as due to those extremely peculiar conditions.

Ralph W. Pope: It is not quite true that the cost of installation is given to the owners of the land, or that they do not pay the cost. That is all figured out, and included in the price that they pay for the land, and it is expected that the installation will be paid for by the consumers in the course of twenty years. As to the low rate, there is absolutely no use for the power in winter. The intent of the irrigation plant is to supply water for irrigation, and no pumping is required during those months when the low rate is given. It is simply a question of competing with coal, for heating, and this is possible where coal is $7 a ton.

I had occasion to inquire about this matter of taking up land, and the replies I got were conflicting. One question that I asked a man, was whether they found men who were willing to take up these small tracts and pay the price, whether or not they were farmers who were accustomed to operating small farms. He said that was one of the difficulties that they had to contend with, that they did not find people ready to take up the land under those conditions. Another man that I met further on, said that where he was, they had had no difficulty of that kind, that there was no trouble at all in finding people who were willing to settle under those conditions. So, there you have the two statements, probably one coming from one part of the country, and the other from another part.

It is certainly a very interesting subject, and since I have learned more about irrigation, I realize that it might have been used in our eastern States to great advantage, and we would have less growling about a drought, such as exists now in many parts, if farmers had utilized the water which is available for such purpose. Of course, this is not always the case, because we do not have the snow-capped mountains in the East to furnish water through the action of the sun, so that the conditions are somewhat different.

J. E. Kershner: I was looking over the table on page 1611, and, a little contrary to a previous speaker, I cannot say that I was struck with the cheapness of the power, except, perhaps, in two instances—0.268 cent and 0.126 cent per kw-hr. If you except those two cases, we can buy wholesale power cheaper than any of the other figures, from Pennsylvania water power companies.

P. M. Lincoln: The extremely low rate for heating, given in the table on page 1613, is possible simply because during the winter time they have no other use for the power, and the only market for their power is for heating purposes. The load factors are given on page 1611. Those prices apply for the load factors actually given. You will notice that where the load factors are high, the prices are low, and where the load factors are low, the prices are high.

H. A. Hornor: There is one fallacy spoken of in the paper that we all know very well, but it seems to me that it is important from the standpoint that the public does not seem to understand it. I refer to the question of transformer losses. I have heard it stated by an engineer of one of the most efficient central stations in the eastern part of our country, that the coal consumption on Sunday about equalled the normal daily coal consumption during the week, due simply to transformer losses. I think the public fails to appreciate that the central station has to carry a transformer load in order to supply its customers with reliable power.

Vladimir Karapetoff: Mr. Newell in his paper does not claim to bring out anything new from an engineering point of view. On the contrary, he emphasizes the fact that the construction used is standard as much as possible. Nor is the paper remarkable for the size of the plants or the hydraulic head used. We have a great many plants in comparison with which the plants he describes are mere dwarfs. But the paper is of great interest because it gives examples of successful hydroelectric work done by our government. Those of us, who, like myself, are believers in government ownership and operation of public utilities, welcome a paper of this kind, because it furnishes us with valuable material for our argument. We have very little inkling of the successful engineering work done by the government. This afternoon we listened to an account of the highly successful work done by the Navy Department in cooperation with private concerns. I welcome Mr. Newell's paper as showing that there is no reason why the government should not engage in a hydroelectric project and bring it to a successful end.

There are just two points about which I would like to ask. On page 1611 the cost in cents per kw-hr. is given. Is it not rather misleading, to give the cost per kw-hr. in a hydroelectric station? The first plant, for instance, operates at an annual load factor of 12.7 per cent, and the cost in cents per kw-hr. is 0.81. The plant could furnish, say, five or six times that amount of power, with very slight increase of expense for additional personnel, and the cost in cents per kw-hr. would be, say, one-fifth of that given. In other words, it seems to me that the last column does not really give the cost, unless it is always quoted in connection with the annual load factor. There ought to be some other basis for comparison. Of course, one basis is the cost of the original construction, per kilowatt capacity.

Another point is this: Some years ago I was asked to investigate into the possibility of certain electrochemical processes in this country that require cheap power, and particularly one of fixation of atmospheric nitrogen, a problem which appeals so much to our imagination. At that time I could not find any place where power could be purchased at a figure that would warrant such an installation. After reading these wonderful figures of cost, I should like to ask those who, like Dr. Hering, understand about electrochemical processes, if nitrogen fixation, or some other fertilizer process, could not be run intermittently during the winter months in connection with one of these plants?

Carl Hering: It seems to me that answers itself, provided such a process can be interrupted; in fact, at a recent meeting of another society, I cited that very case as one in which power could be "stored" more cheaply and better than it can be stored as water in reservoirs. I refer to those electrochemical plants which can be run when the water power exists, and can be shut off when it does not exist. In that way the product can be produced while the water is flowing, and can be sold at one's leisure, which is in effect a process of storing the energy. There is no doubt that this can be done with some electrochemical processes, but not with all of them.

In connection with what Prof. Kershner said, I notice at another place in the same table, on page 1611, that these costs are stated to be those at the switchboard, and not for power delivered to the premises. It is one thing to generate power, and another thing to transmit it and deliver it; the cost of transmission is sometimes great. One would have to run his own lines to the switchboard, to use the power at these rates. If the cost of distribution is added to the figures in the lower part of the table, the energy is by no means cheap.

Mr. Bender: I would like to ask, also, in connection with those figures, if interest is included in those costs. That would be another item to be taken into account.

P. M. Lincoln: I am not sure of that, but I think interest is included, but at a very low rate, a rate at which the government can borrow money.

H. Goodwin, Jr.: Mention has been made of the use of water for irrigation in the orange orchards in Southern California, and it might be of interest to try to get a little nearer to the point of view of the men operating those orange groves. Two years ago I was at Santa Paula, about 100 miles north of Los Angeles, at the oldest lemon grove in Southern California, which is now growing many oranges, too. They own the water rights of a small stream which supplies sufficient water for irrigation all through the irrigation season. The grade at which the water reaches the grove is the highest of the level section, but above that are many acres on a steep hill which were used only for hay. (Their hay is a mixture of barley and oats, and not our timothy and clover). There was so much money in oranges that they were considering putting about 50 acres of this land into oranges. To do that they would have to pump water to the top (by electric power, of course).

At the rate they receive for such purposes it was found that it would cost them $18 a day for pumping water up over this hill of 50 acres. That was no hindrance at all to them. They went right ahead with the proposition. Eighteen dollars a day is nothing at all to them. But if you tell a farmer here in the east to spend $18 a day for pumping water over his land, so as to double his output, he will tell you you are crazy.

There is another interesting point about the way they use the power. One very large item of expense of which Mr. Hornor has spoken is transformer expense. They avoid this by using 2400 volts just as we would use 110 volts here. All the pumps are 2400 volts. They run the overhead lines on ordinary D.G. glass insulators, come into a little shack through porcelain tubes, erect some current transformers and a meter, put a couple of knobs on the ceiling, and drop down to the motor in the center of the floor. This wiring does not cost them much over $20 or $25, which is a decidedly different proposition from our transformer installation, and other work we have to do in this section. Yet I could not find any case of death by electrocution of any of the men working around these groves.

The point of view of the Southern Californian is so different from our own in regard to spending money on farms, that it should be of interest to us to look at things occasionally from that viewpoint.

F. H. Newell (by letter): The above discussion indicates that the object of this paper has been correctly understood and that it is necessary only to answer one or two questions.

With reference to the taking up the reclaimed land, there has been relatively little difficulty or delay in this, as the public lands are practically given away under condition that the cost of bringing water to these lands, including the expenditures for the hydroelectric power plants and other accessories, is repaid by the land owner within 20 years. The time for repayment was originally set at 10 years, but by Act of Congress of August 13, 1914, it was extended without interest to 20 years. Thus the land owners are called upon to pay an average of only 5 per cent on the principal, not interest, for 20 years and then all payments cease, except for operation and maintenance. The amount paid, however, during the first few years is less than 5 per cent, but during the later years of the 20-year period is as high as 7 per cent, being adjusted so as to make complete payment of construction cost within the 20-year period.

In regard to the cost of lands which have passed into private ownership, the prices set on these have been high, but the inflation has practically ceased, and lands irrigated by the government are now being held at more moderate prices than in the past few years. The difficulty has not been so much that of disposing of the land as in getting it utilized to the best advantage after it has passed into the hands of homestead entrymen or purchasers. The lack of capital and high interest charged on borrowed money has delayed development, but with the gradual growth of the country and increase of small industries made possible by cheap power, there is a steady improvement in agricultural conditions.

One of the striking needs, as pointed out in the above discussion, is that of some method of storing this cheap power, one which may possibly be brought about by electrochemical processes. Here is a field for invention which it is hoped will be entered upon at an early date.

The experience which is being acquired in construction, operation and maintenance by the government of works of this character cannot fail to be of value, particularly at the present time when there is general agitation for enlargement of governmental functions. This paper will have fulfilled its purpose if it has attracted attention to some of the opportunities and limitations of such governmental undertakings.

Presented at the 301st Meeting of the American Institute of Electrical Engineers, New York, November 13, 1914.

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THE CORONA PRODUCED BY CONTINUOUS POTENTIALS

BY STANLEY P. FARWELL

ABSTRACT OF PAPER

This paper deals with an experimental investigation of the corona around small wires as produced by continuous potentials up to 15,000 volts. The continuous potentials were obtained from a series of 500-volt generators.

The wire and coaxial cylinder method was employed for a number of experiments. Critical voltages and characteristic potential difference and current curves were obtained for different sized wires. The effect of lowering the pressure in the cylinder upon appearance of corona, critical voltage, and current, was studied. It was found that the appearance of the corona depended upon the polarity of the wire; positive polarity gave continuous glow, while discontinuous beaded appearance characterized the negative corona, the number of beads being a function of the pressure and the potential difference for a given size wire. A short arc in series affected the nature of the discharge by superimposing a high-frequency current upon the direct current. Characteristic curves were taken to show the effect of varying pressure, moisture and temperature. An increase of pressure inside the closed cylinder was produced by the application of a potential difference greater than the critical value; this increase is due to ionization.

Corona in the case of parallel wires was studied by taking characteristic curves and exploring the field. Field exploration showed anode fall of potential greater than cathode. Corona accompanied by mechanical effects on wires: deflection on both wires and circular vibration of positive wire.

THE DIRECT-CURRENT CORONA

IN alternating-current transmission lines at very high voltages a loss occurs by dissipation of power into the air. This is accompanied by luminosity of the air surrounding the conductors, and to this glow the name "corona" has been given. Loss begins at some critical voltage, depending on the size and spacing of the conductors, etc., and increases very rapidly above this voltage. This corona effect is of considerable importance, as it involves a power loss of some magnitude on long lines, and it has been studied by Steinmetz, Scott, Ryan, Mershon, Jona, Peek, Whitehead and others.

The corresponding direct-current case, although not of such immediate importance, is yet of considerable interest in view of the high-tension direct-current developments on the continent of Europe. The only work of much importance along this line has been done by Watson[1] and Schaffers.[2] Watson has carried out a number of tests of wires strung axially along a cylindrical tube and also on two parallel wires out-of-doors. The wires used were of various diameters between 0.70 mm. and 12.76 mm. The source of power was an influence machine of special design and large output which would give any potential required up to 70,000 volts.

The electric stress at the surface of a wire subjected to electric potential is as follows:

Wire in cylinder:

$$R_{max.} = \frac{V}{a \log_e \frac{b}{a}}$$

Two parallel wires:

$$R_{max.} = \frac{V}{2_a \log_e \frac{d}{a}} \left(1 + \frac{a}{d}\right)$$

where V = potential difference between wires, or between wire and cylinder,
a = radius of wire,
d = distance apart of wires,
b = radius of cylinder.

Of these formulas, the first is exact, while the second is only approximate, but is very nearly correct for all ordinary cases where a is small compared to d, and the wires are well above the earth.

The value $R_{max.}$ in the above formulas is called by some writers the "critical surface intensity" and is extensively used in expressing the results of tests. It has been well established by Watson, Whitehead and others that this critical surface intensity increases very greatly as the radius of the wire decreases. A comparison made by Whitehead of his results for this intensity in the case of alternating potentials with the similar values deduced by Watson for continuous potentials, shows that for a given size of wire it requires the same voltage to produce corona in both cases, if the maximum value of the alternating potential be used.

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[1] Watson, *Electrician*, London, Vol. 63, 1909, p. 828; Vol. 64, 1909-10, pp. 707 and 776.

[2] Schaffers, *Comptes Rendus*, July 1913, p. 203.

For the case of a wire in a cylinder Watson found some differences between the case when the wire was positive to the cylinder and when it was negative to it, these differences occurring both in the appearance of the corona and in the measurements relating to it.

The article by Schaffers referred to above, gives the results of a study of the ionization in cylindrical fields, using wires of various diameters ranging from 0.0006 cm. to 0.70 cm. in tubes ranging from 0.70 cm. to 11.7 cm. in diameter. He says nothing of the source of potential used or of the appearance of the coronas. He finds that for the larger size wires the positive corona appears at a lower voltage than the negative and that for the smaller sizes, the reverse is true, the radius 0.01 cm. separating these two regions. Another conclusion reached by this investigator is that the nature of the material of the wire is without effect upon the coronal voltage, at least if the wires are not very fine.

When this investigation was undertaken, there was no physical theory advanced which explained the phenomena observed. During the progress of this work, however, two theories were published, one by Bergen Davis (TRANS. A.I.E.E., this volume, part 1, p. 589) the other by J. E. Townsend (*Phil. Mag.*, May, 1914,) which try to explain the phenomena by ionization through collision. Both theories neglect the influence of light and a number of phenomena that have been discovered in the present investigation.

In view of the scarcity of certain data as to the corona at continuous potentials, the object of the work described in this paper has been to extend our experimental knowledge in this direction.

DETAILS OF EXPERIMENTAL APPARATUS

The source of the continuous potentials employed was a battery of small continuous-current generators connected in series. There were thirty of these, each rated as follows: Amperes, 0.5; watts, 250; speed 1700; volts, 500; shunt-wound. The potential available, then, was 15,000 volts when the machines were run at normal voltage.

These generators were arranged in two sets, one of twenty machines and the other of ten. The generators were self-excited and could be put into service by closing a small knife-switch in each field circuit. Voltage control was obtained in this manner and by controlling the speed of the set by field control of the driving motor. A fine adjustment of voltage was obtained by means of a rheostat in the field circuit of one of the generators. The series connection between the machines was permanent.

The diagram of connections in Fig. 1 is self-explanatory. The apparatus labeled "Short Arc" consists of an air gap between the head of a tack and a copper wire. This spark gap could be cut out of the circuit by closing a shunt around it. Special care was taken in setting up the apparatus to thoroughly insulate it from the ground, except that the negative terminal of the generating apparatus was grounded, in order to minimize the danger from shock.

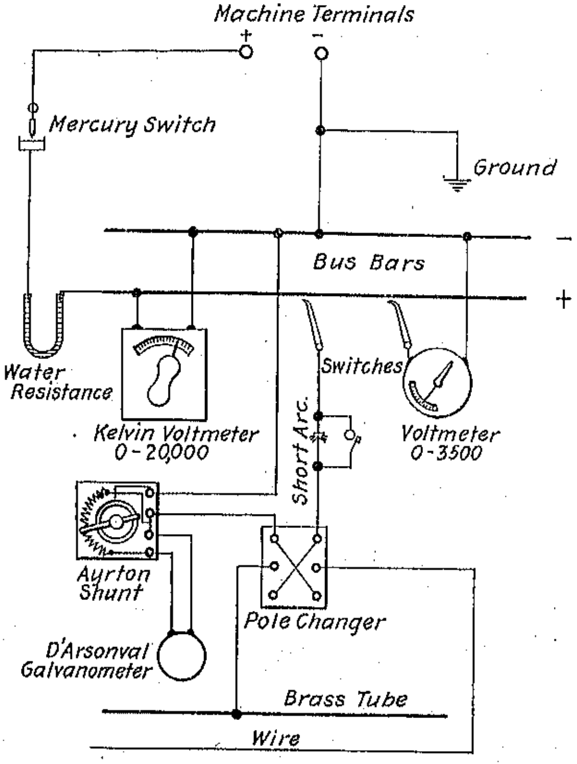

FIG. 1—DIAGRAM OF CONNECTIONS

The voltage between the busbars and hence, with sufficient accuracy, the difference of potential impressed upon the corona apparatus, was measured by means of electrostatic voltmeters. For the lower ranges an instrument was employed having a range of 3500 volts and accurate to within one per cent. This conclusion was reached by comparing its indications with those obtained by adding the voltages of the machines used, as given by a 750-volt direct-current portable voltmeter which had been carefully calibrated.

For the measurements of the higher differences of potential a vertical type Kelvin electrostatic voltmeter was used. This instrument had three ranges, of 5000, 10,000, and 20,000 volts, which could be secured by hanging the proper weights from a lug at the bottom of the needle. Only the 10,000 and 20,000 ranges were used. The lower part of the 10,000 range was calibrated by the same method as for the lower range voltmeter, as well as by measuring the voltages indicated by the portable voltmeter when a high resistance was inserted in series with it. This high resistance was made of a U-tube containing alcohol into which two platinum wires dipped. This resistance was kept from heating by immersing it in a mixture of ice and water. Under these conditions the resistance was very constant for the small currents used.

The higher ranges of this voltmeter were calibrated by reference to an attracted disk electrometer. This instrument had a disk 5.5 cm. in diameter. The aperture of the guard-ring was 5.9 cm. in diameter and the outside diameter of the guard ring was 16.0 cm. A separation of 1.5 cm. was used between the disk and the lower plate.

Due to the non-uniformity of the field at the edge of the disk, an edge correction must be applied to the indications of the electrometer. This edge correction is treated by Maxwell in Vol. 1 of his "Electricity and Magnetism" and the conclusions reached are briefly as follows:

Let

R = radius of disk
R' = radius of aperture
D = distance between plates
A = effective area of disk
$\alpha = 0.220635\,(R'-R)$
W = wt. in grams to balance.

Then

$$V = D\sqrt{\frac{8\,\pi\, g\, W}{A}}$$

where

$$A = \frac{1}{2}\pi\left[R^2 + R'^2 - (R'^2 - R^2)\frac{\alpha}{D + \alpha}\right]$$

Using the numerical constants of the instrument as given above, there results:

$$\alpha = 0.044$$
$$A = 25.474 \text{ sq. cm.}$$

We may write $V = k\sqrt{W}$, where k is the constant

$$D\sqrt{\frac{8\pi g}{A}}$$

Then $k = 13{,}992.3$. By a similar series of operations we find that for plates 1 cm. apart, $k = 9357.6$.

By use of the value $k = 14{,}000$, which is nearly enough correct, the values of W to balance for different voltages were calculated, and a test run to determine how closely these values checked with the actual weights required for a balance when the voltages indicated by the electrostatic voltmeter were impressed. A consideration of these figures with due regard to the accuracy of the determinations led to the final calibration.

D'Arsonval galvanometers were used to measure the discharge currents obtained with the various pieces of corona apparatus. Most of the characteristic curves were taken with a very sensitive galvanometer which had a small coil, a resistance with connecting wires of 326.0 ohms, and was practically dead-beat. For the later moisture and pressure determinations which extended over some days, a less sensitive instrument was used. This had a heavier coil, a resistance with connecting wires of 849.5 ohms and a period of six seconds. Its figure of merit was about five times that of the first instrument.

The figure of merit of these galvanometers was determined from time to time, using accurate resistances of high value and as a source of e.m.f. either a dry cell or a standard cell. In the case of the dry cell, its e.m.f. was determined from the indications of an accurate laboratory standard voltmeter. An Ayrton universal shunt was used in connection with the galvanometer. This shunt box had five coils connected between contact points.

PRELIMINARY EXPERIMENTS

When this work was first undertaken, it was not apparent from the limited literature of the subject what one might expect in the way of coronal phenomena which might be produced by potentials up to the total voltage of the generating sets, namely 15,000 volts. No glow could be obtained between flat plates; only an arc. Then an investigation was begun to find out what kind of terminals would have corona produced between them by the comparatively low voltage available.

A brass rod, 0.637 mm. in diameter, was located axially along a tube 4.45 cm. in diameter and the full voltage of the sets was impressed. No effect was visible. Then provision was made for exhausting the tube, and at about one-quarter atmosphere a discharge took place. This took the form of brilliant radial purple arcs terminating in bright blue "stars" on the walls of the tube. These arcs were in constant motion around the wire and along the tube and reminded one of a pinwheel. A fairly large size wire was substituted for the rod and still no corona could be obtained at atmospheric pressure.

Recourse was next had to large influence machines. It was known that the silent discharge between points was of the same nature as the corona between wires and it was reasoned that if the e.m.f. of an influence machine were impressed between small parallel wires, a discharge would take place between them. Two bare No. 40 wires were stretched parallel to one another and a few centimeters apart, and a silent discharge was found to take place between them. The appearance of the discharge was at once seen to depend upon the polarity. The discharge was discontinuous, small brushes on the negative wire corresponding to sections of uniform glow on the positive wire. The brushes were in a more or less constant movement back and forth along a short path, but they appeared to be more or less evenly spaced along the wires. It was also noticed that the wires vibrated and that the negative wire bowed in toward the positive, which bowed away from the negative. It was as though a wind were blowing across the wires.

Another experiment was tried with a No. 40 wire above a sheet of tinfoil. With this arrangement and wire positive, a continuous glow appeared along the wire, while when the wire was negative the discontinuous brush discharge appeared again. Vibrations were also noticed with this apparatus.

A mandolin steel "*E*" string, 0.24 mm. in diameter, was strung along the axis of a brass tube of about 3 cm. diameter and the wire and tube were connected to opposite polarities of the influence machine. If the wire was positive, a continuous bluish glow of markedly uniform appearance appeared along the wire. When the wire was negative, the discharge was in constant movement and seemed to consist of countless purple streamers or brushes. There seemed to be no appearance of regularity of spacing of isolated brushes.

When these tests were run it was noticed that the main discharge knobs on the machine could be moved together until they almost touched before a spark would pass. This indicated that the difference of potential between the parallel wires, for example, could not be very high, not over 10,000 volts perhaps. This fact suggested that similar discharges with small wires should be produced by the continuous potentials from the generating sets. So the experiments were carried out again and it was found that the same effects were produced by the generators.

The crude tube apparatus was fastened to a board by means of nails driven into the wood and bearing against the wall of the tube. Connection was made to the tube by wrapping a wire around one of these wires. This wire became loose and separated 0.01 inch or so from the tube. The consequence was that a short arc was established between the wire and the tube. The presence of the arc caused a marked difference in the character of the positive discharge. With a potential difference of about 8000 volts and the wire positive to the tube, a very active discharge took place between the wire and tube. The whole tube appeared filled with a bluish glow particularly brilliant around the wire, where an uneven effect was apparent, resembling a brush discharge. The discharge was unstable and variations in the arc produced marked variations on the discharge. After the bluish glow had continued for some minutes, the nature of the discharge became suddenly different. Purple arcs appeared, of much the same nature as those mentioned above in connection with the discharge from a rod at low pressure. After a while the discharge would resume its former character and then the process would repeat. The arc between the nail and tube appeared bluer while the whirligig discharge was going on. A small wire was slipped in to bridge the gap between nail and tube and then the discharge became merely a faint blue glow of a uniform nature, apparent only in the immediate vicinity of the wire. With the gap closed, the wire negative, an entirely different discharge took place. Small purple brush-like discharges were clustered irregularly along and around the wire and these held their positions fairly constant. When the arc was again introduced, the discharge appeared somewhat dimmer, although keeping its nature about the same, as far as could be seen by looking from the end of the tube.

CHARACTERISTIC CURVES AT ATMOSPHERIC PRESSURE

In order to study the influence of diameter of wire upon critical voltage and discharge current, a number of different sizes of bare wire ranging from No. 40 to No. 10, copper, were obtained from the manufacturers and an apparatus was constructed in which the tests could be carried out. This apparatus consists essentially of a brass tube 4.45 cm. in internal diameter, well insulated from its support and provided with means for accurately and tightly stretching a wire along its axis. The tube was provided with a small branch tube through which the air could be exhausted. The centering of the wire was accomplished by passing it over hard-rubber bridges in which there were notches axially located with respect to the tube and stretching it tightly by means of a mandolin tension-head. In order to limit definitely the length of the wire from which a discharge could take place, glass plates were sealed to the ends of the tube and the wire passed through holes in them about 3 mm. in diameter. For most of the characteristic voltage-current curves, the exhaust tube and the holes in the plates were left open and the air in the tube had the same constitution as that in the room, at least at the beginning of the test.

In order to make sure that no current would flow through the apparatus except that through the air, a small wire was arranged so that the tube was in the same condition as for a test except that none of the wire extended inside of the cylinder. Then differences of potential were applied up to 10,000 volts and the currents measured. It was found that even at the highest voltage the current was insignificant.

For the first wires tested, a start was made at a low voltage and the currents taken by small increments on the way up. It was soon found that the current flowing was negligible until the voltage approached that necessary for a visible glow, and therefore later tests were started at a voltage somewhere near the critical voltage. For each voltage the deflection of the galvanometer was read for both polarities of the wire.

When the wire was positive and the voltage neared that necessary to cause a visible glow, a very marked jump of the deflection would occur and a further increase of the voltage caused the current to increase very rapidly. The voltage at which this sudden increase of the deflection took place was called the "critical voltage." "Visible glow" was taken to mean the first appearance of light in the case of the wire positive. This glow appeared suddenly for all but the smallest wires, in which case the dimness of the glow made it hard to tell just where the limit of visibility was.

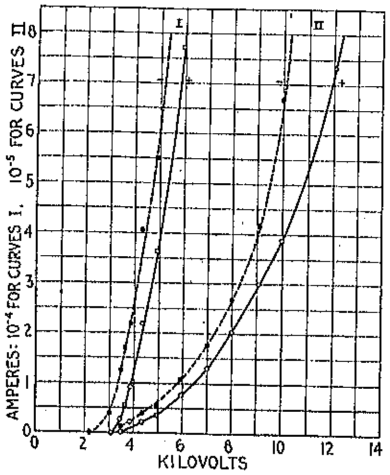

FIG. 2—CHARACTERISTIC: SILVER WIRE 0.037 MM. DIAMETER

Tube 4.45 cm. diameter, 25 cm. long; temperature 20.7 deg. cent.; relative humidity 45.3 per cent; barometric pressure 736.48 mm.

As has been noted, the presence of dirt or dust particles on the wire, when negative, has a marked effect upon the discharge. Often a spot or two on the wire would glow long before the wire as a whole was luminous. Due to this fact there is no definite critical voltage as in the case of the positive polarity, for the initial jump of the deflection is much a matter of chance. But as the voltage is increased, there occurs a critical voltage at which a flickering glow can be seen along the wire preliminary to the spreading of the discharge from a few spots over the whole wire. This phenomenon occurs at a definite voltage for a given size wire and it is this voltage which is given in the tables under "visible glow" for the negative polarity.

Readings of wet and dry bulb thermometers and an aneroid barometer were taken for each test and the per cent relative humidity was calculated. The barometer was checked from time to time by reference to a very accurate mercurial barometer.

The silver wire used in these tests was really silver wire with a platinum core, known as "Wollaston" wire. This wire was used both in its original state, diameter 0.0517 mm., and with some of the silver dissolved off, giving wires of average diameter 0.027 and 0.037 mm.

The tungsten wire was of the sort used in 25-watt lamps.

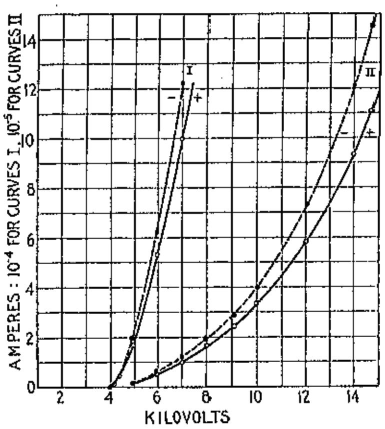

FIG. 3—CHARACTERISTIC: NO. 40 B. &. S. COPPER WIRE, 0.077 MM. DIAMETER

Tube 4.45 cm. diameter, 25 cm. long; temperature 25 deg. cent.; relative humidity 41.6 per cent; barometric pressure 745.3 mm.

The diameters of the very small wires were obtained by the use of a microscope fitted with a stage ruled with parallel lines.

VARIATION OF CRITICAL VOLTAGE AND GLOW VOLTAGE

Tables I and II give data on critical voltages and the voltages required to produce continuous visible glow for wires of diameters ranging from 0.027 mm. up to 1.28 mm., and are plotted in Fig. 2. Similar tables for Figs. 3, 4 and 5 are omitted. A study of these data showed the following facts:

a. For the smaller sizes, the critical voltage is considerably lower than the glow voltage, showing that quite a current exists before a luminous discharge occurs. This applies for wire positive.

TABLE I

Silver Wire—Diameter 0.027 mm.
Temperature 26.6 deg. cent.
Relative Humidity 54.4 per cent.
Barometric Pressure 741.55 mm.

	+	—
Critical Voltage	2100	1880
Visible Glow	2720	2520

Potential Difference	Galv. defl. in mm.		Shunt factor		Current in 10^{-4} amp.	
	+	—	+	—	+	—
1750	1.1	1.2	1.0	1.0	0.000032	0.000035
2100	25.0	60.0	1.0	1.0	0.00072	0.00173
2500	66.7	50.7	1.0	11.09	0.00192	0.0162
2800	137.0	101.0	1.0	11.09	0.00394	0.0322
3000	18.2	147.0	11.09	11.09	0.0058	0.0469
3200	33.0	21.1	11.09	110.9	0.0105	0.0674
3500	101.0	36.7	11.09	110.9	0.0322	0.117
3860	30.9	69.0	110.9	110.9	0.0986	0.220
4350	66.2	122.8	110.9	110.9	0.212	0.392
4920	114.8	18.4	110.9	1109	0.335	0.588
5950	23.9	35.2	1109	1109	0.763	1.12
7000	39.4	56.7	1109	1109	1.26	1.81
8000	60.7	87.5	1109	1109	1.94	2.80
9100	82.0	113.0	1109	1109	2.62	3.61
			wire broke			

Wire rough: 0.027 is average of many readings.
Figure of merit of galvanometer 2.88 × 10^{-9} amp. per mm. defl.

TABLE II

Silver Wire—Diameter 0.037 mm.
Temperature 26.7 deg. cent.
Relative Humidity 45.3 per cent.
Barometric Pressure 736.48 mm.

	+	—
Critical Voltage	3100	2200
Visible Glow	3380	3230

Potential Difference	Galv. defl. in mm.		Shunt factor.		Current in 10^{-4} amp.	
	+	—	+	—	+	—
2150	1.5	2.1	1.0	1.00	0.00004	0.00006
3000	4.0	117.0	1.0	11.09	0.00011	0.0374
3500	85.7	39.3	11.09	110.9	0.0274	0.126
3650	117.7	53.3	11.09	110.9	0.0565	0.170
3860	29.0	68.8	110.9	110.9	0.0926	0.220
4350	68.8	127.7	110.9	110.9	0.220	0.407
4920	114.3	172.7	110.9	110.9	0.365	0.551
5950	242.0	34.4	110.9	1109	0.773	1.10
7000	41.0	56.0	1109	1109	1.31	1.79
8000	64.0	84.0	1109	1109	2.04	2.68
9100	94.7	131.0	1109	1109	3.02	4.18
10000	121.7	21.0	1109	11090	3.88	6.7
12075	23.0	58.7	11090	11090	7.35	18.8
14000	... wire broke—		arc.	...	....	....

Figure of merit of galvanometer 2.88 × 10^{-9} amp. per mm. defl.

b. The smallest size for which there is no current for wire positive before glow appears is No. 36, diameter 0.136 mm.

c. For sizes larger than No. 36, current and glow appear simultaneously, for wire positive.

d. For wires from about No. 26 up, for the negative polarity, the current and the visible glow appear simultaneously, as a general rule.

Fig. 6 gives curves showing the variation of the glow voltages with the radius of the wire. From these curves the following conclusions can be drawn:

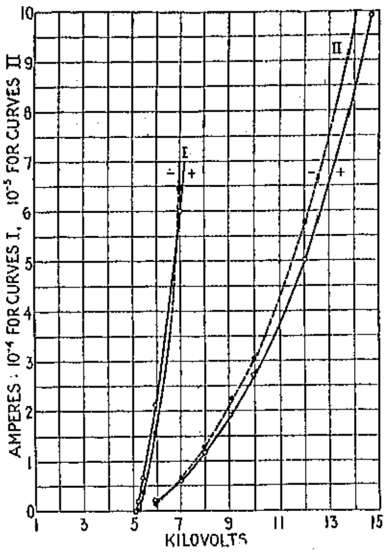

FIG. 4—CHARACTERISTIC: NO. 36 B. & S. COPPER WIRE, 0.135 MM. DIAMETER

Tube 4.45 cm. diameter, 25 cm. long; temperature 25 deg. cent.; relative humidity 45 per cent; barometric pressure 733.85 mm.

e. For the smaller sizes, the negative glow appears before the positive.

f. For the larger sizes the positive glow appears before the negative.

g. The diameter 0.075 mm. is the boundary between these two regions.

Schaffers has noted this crossing of the curves for the starting points of the positive and negative corona and he gives 0.01 cm. radius as the boundary value between the two regions. He does not specify what he considered as the starting point of the negative corona and therefore it is not practicable to compare his value with that given above.

VARIATION IN THE NATURE OF CORONA

During the tests for the characteristic curves a close watch was kept over the appearance of the corona, and there are given below some of the characteristic changes and phenomena which were noted.

For the entire range of diameters there was very little change in the appearance of the positive corona, except for an increase in brightness with the voltage. It always presented a quiet, uniform, continuous, bluish glow. For high voltages the opening and closing of the circuit was attended by a flash of bluish light in the tube and if care was not taken to perform these operations quickly, there was likelihood of an arc starting between the wire and the tube, with the result that the wire, if it was small, was burned in two.

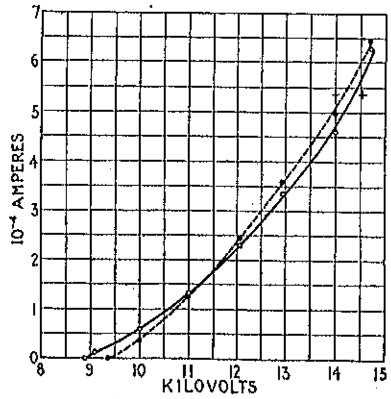

FIG. 5—CHARACTERISTIC: No. 26 B. & S. COPPER WIRE, 0.41 MM. DIAMETER

Tube 4.45 cm. diameter, 25 cm. long; temperature 26 deg. cent.; relative humidity 29.2 per cent; barometric pressure 740.86 mm.

There was considerable change, however, in the appearance of the negative corona with increase of diameter and voltage. The negative corona on small wires starts with a bright spot or two, followed by a mixture of bright spots and brushes as the voltage is increased. With still increasing voltage there is more of a continuous brush-like effect and the discharge becomes quite purple. For the highest voltages the corona is brilliant, purple, continuous, and in constant movement. For the smallest sizes, the negative corona is likely to take the form of a discharge consisting of isolated, more or less evenly spaced brushes. Marked regularity of spacing has often been observed. The discharge is noiseless for wires up to No. 26 (0.24 mm.), for which diameter a slight hissing appears. As the diameter increases, the hissing grows louder and the diameter of the corona increases.

In the case of the larger size wires, it is the general rule for the continuous negative brush discharge to appear immediately when the critical voltage is reached.

No flash at make or break of the circuit was observed when the wire was negative.

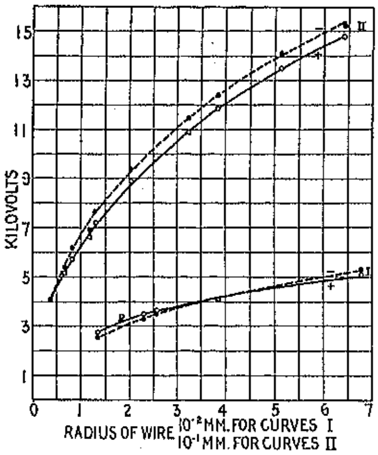

FIG. 6—DIFFERENCE OF POTENTIAL TO CAUSE CONTINUOUS GLOW, AS FUNCTION OF RADIUS OF WIRE

Tube 4.45 cm. diameter, 25 cm. long.

DISCUSSION OF THE CHARACTERISTIC CURVES

A critical comparison of the characteristic curves in Figs. 2 to 5 brings out the following points:

a. For a given voltage, the current increases with decrease of diameter of the wire, also with decreasing pressure.

b. For wires smaller in diameter than No. 40 (0.077 mm.), the current for negative polarity of the wire is always greater than for positive polarity.

c. In the case of No. 40 wire the currents for opposite polarities coincide very accurately for a small rise in voltage above the critical value, and then the negative current becomes and remains the larger.

d. For sizes larger than No. 40, the curves for the two polarities cross. For the lower voltages the positive current is the greater, and *vice versa* for the higher voltages.

e. The characteristic curves become more nearly parallel to the current axis as the diameters increase.

Table III contains the critical and the glow voltage as functions of the radius of the wire, Table IV the glow voltage and the maximum electric intensity at the surface of the wire as function of the radius. While with increasing radius the glow voltage increases, the electric intensity E at the surface of the wire decreases. Fig. 6A shows this relation graphically. As has been found by previous investigators, this electric force E can be represented by the following law: $E = a + \frac{b}{\sqrt{R}}$. For the smallest wires, there are deviations from this formula, as we should expect, because the critical voltage and the glow voltage differ from each other and as very probably there is a distortion of the field due to ionization before the glow sets in as in the case of two parallel wires. For the positive wire we found $a = 31.6 \times 10^3$; $b = 8.47 \times 10^3$, for the negative wire $a = 35.0 \times 10^3$; $b = 8.06 \times 10^3$.

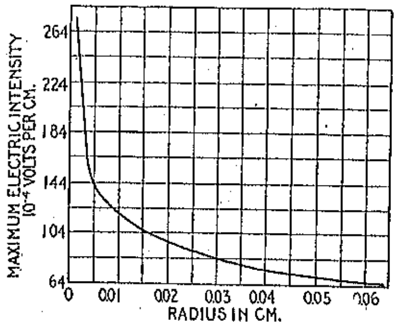

FIG. 6A

INFLUENCE OF PRESSURE ON CORONAL CURRENT

The effect of variation of pressure on the voltage to cause continuous glow was studied for a No. 26 wire by varying the pressure in the tube from 768 mm. down to 2 mm., and the results are given in Table V and shown by curves in Fig. 7. Below about 20 mm. pressure it was found impossible to get a negative uniform glow. Instead of this there appeared a series of beads approximately equally spaced along the wire.

It was found that measurements of the coronal current for

TABLE III

CRITICAL DIFFERENCE OF POTENTIAL TO CAUSE CONTINUOUS GLOW, AS FUNCTION OF RADIUS OF WIRE.

Radius in mm.	Material	Critical voltage	Positive glow	Critical voltage	Negative glow.
0.0135	Silver	2100	2720	1880	2520*
0.0185	Silver	3100	3380	2200	3230*
0.0230	Tungsten	3380	3500	2800	3300
0.0258	Silver		3630		3500
0.0386	No. 40 Copper	3080	4060	3860	4060
0.0678	" 36 Copper	5120	5140	4350	5320
0.0825	" 34 Copper		5710		6140
0.120	Steel " E " String	6000	6600	6760	6840
0.130	" 30 Copper	7180	7180		7660
0.205	" 26 Copper	8900	8900	9370	9370
0.325	" 22 Copper	9700	10880	11440	11440
0.385	" 20 Copper	11850	11850	12075	12400
0.512	" 18 Copper	13500	13500	14040	14120
0.642	" 16 Copper	14700	14700	15220	15220

*These values uncertain on account of dimness of glow.

TABLE IV

R cm.	*V* +volts.	*E* +volts per cm.	*E* +calcul.	*V*—volts.	*E*—volts per cm.	*E*—calcul.
0.00135	2720	2.74×10^5	2.62	2520	2.52×10^5	2.55
0.002185	3380	2.58	2.29	3230	2.45	2.23
0.0023	3500	2.25	2.09	3300	2.08	2.04
0.00258	3630	2.12	1.99	3500	2.02	1.94
0.00386	4060	1.66	1.67	4060	1.66	1.65
0.00678	5140	1.31	1.34	5320	1.36	1.33
0.00825	5710	1.25	1.25	6140	1.21	1.21
0.012	6600	1.07	1.09	6840	1.09	1.09
0.013	7180	1.07	1.06	7660	1.14	1.06
0.0205	8900	0.93	0.91	9370	0.99	0.92
0.0325	10880	0.80	0.79	11440	0.83	0.80
0.0385	11850	0.77	0.75	12400	0.79	0.76
0.0512	13500	0.71	0.69	14120	0.73	0.71
0.0642	14700	0.65	0.65	15220	0.64	0.64

the same wire gave different results on different days and it was considered advisable to find out the influence of pressure for a range around atmospheric pressure in order that the current readings for the different sizes of wire might be reduced to a 760-mm. basis. Therefore a series of characteristic curves was taken for different pressures with dry air in the tube to do away with any effect which might be due to the moisture in the air. Fig. 8 shows the results obtained. These curves show a marked increase in the current for a relatively small decrease in the pressure. The curves also show an unsymmetrical spacing, which suggests the presence of some disturbing factor.

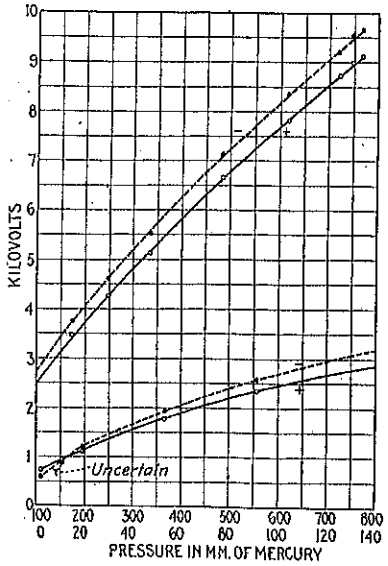

FIG. 7—GLOW VOLTAGE AS FUNCTION OF PRESSURE IN TUBE

No. 26 B. & S. copper wire, diameter 0.41 mm.; tube 4.45 cm. diameter, 25 cm. long; dry air at 25 deg. cent. in tube.

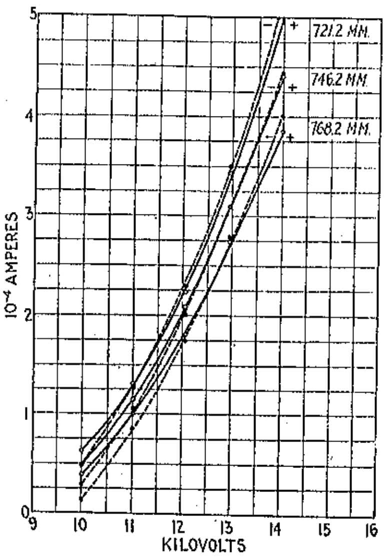

FIG. 8—CHARACTERISTICS FOR VARYING PRESSURE

No. 26 B. & S. copper wire, diameter 0.41 mm.; tube 4.45 cm. diameter, 25 cm. long; dry air at 25 deg. cent. in tube.

In a number of preliminary experiments it was found that it was not possible to repeat observations if the tube was closed and the air not changed. In order to do away with any disturbing effects due to moisture in the air and possible changes in the constitution of the air in the tube, an arrangement was devised for supplying dry air which could be pumped through the tube out into the atmosphere. The air was dried by passing it through two wash-bottles containing concentrated sulphuric acid and then through a tube containing soda-lime. A No. 40 wire was strung in the tube and as the atmospheric pressure varied from day to day, series of readings were taken as given in Table VII. The general decrease of current with increase of pressure is apparent. The readings for the extreme pressures 735 mm. and 754 mm. are shown in Fig. 9. These curves show quite a regular variation in the effect of pressure with a tendency toward a greater effect upon the current for negative polarity. This regularity would seem to indicate that the

TABLE V

VARIATION OF CRITICAL VOLTAGE WITH PRESSURE.

No. 26 B. & S. Copper Wire. Diameter 0.41 mm. Dry Air at 25 deg. cent.

Pressure in mm.	Potential Difference for Continuous Glow	
	+	—
2.0	720	*580
10.9	940	*870
18.9	1110	1200
53.2	1770	1920
91.3	2350	2580
173.5	3450	3750
248.5	425	4610
334.8	5120	5520
483.6	6660	7120
616.6	7800	8330
720.0	8730	9210
746.0	8980	9530
768.3	9100	9640

No continuous glow obtainable—voltage is that of formation of beads.

TABLE VI

p in mm.	*V*— in volts.	*E*— in volts per cm. × 10^4	*V*—	*E*—	*E* average	*E* calculated
2.	720	0.765	580	0.615	0.69	0.36
10.9	940	0.998	870	0.925	0.96	0.85
18.9	1110	1.18	1200	1.275	1.22	1.14
53.2	1770	1.88	1920	2.04	1.96	2.01
91.3	2350	2.50	2580	2.74	2.62	2.72
173.5	3450	3.60	3750	3.99	3.79	3.97
248.5	4250	4.51	4610	4.90	4.71	4.87
334.8	5120	5.42	5520	5.86	5.63	5.83
483.6	6660	7.08	7120	7.55	7.31	7.36
616.6	7800	8.29	8330	8.85	8.57	8.60
720.0	8730	9.28	9210	9.80	9.54	9.21
746.0	8980	9.51	9530	10.1	9.80	9.70
768.3	9100	9.67	9640	10.2	9.93	9.89

discordant results obtained in the preliminary experiments were due to the presence of other factors than mere change of the pressure.

To determine what effect, if any, the confining of air in a closed tube had upon the coronal current, a series of tests was run under constant pressure with various conditions as to the closing of the tube, the renewal of the air, etc. The erratic results follow no evident relations and indicate that confinement of the air has a great effect upon the coronal current and also upon the critical and visible glow voltages. Such an effect does not appear strange when one thinks of the quantities of ozone formed and possibly other products, which, when the tube is closed, must remain inside and thus change the character of the gas to a considerable extent. It must be concluded from these tests that it is unsafe to compare results obtained in a closed tube with those obtained where there is a plentiful supply of fresh air.

TABLE VII

EFFECT OF PRESSURE.

No. 40 B. & S. Copper Wire. Diameter 0.077 mm.
in
Tube of diameter 4.45 cm.; length 25.0 cm.
Dry air in tube.
Currents in 10^{-4} amp.

Potential dif-ference	735 mm.		738 mm.		749.0		754.0	
	+	−	+	−	+	−	+	−
4000	0.00025	0.00030	0.000076	0.000051	0.000015	0.000015	0.000015	0.000015
5000	0.205	0.176	0.181	0.210	0.150	0.169	0.150	0.169
6000	0.553	0.676	0.557	0.703	0.468	0.611	0.468	0.602
7000	1.06	1.34	1.06	1.35	0.859	1.17	0.900	1.16
8000	1.76	2.28	1.73	2.32	1.38	1.90	1.53	2.02
9000	2.58	3.35	2.53	3.25	2.15	2.86	2.28	2.90
10000	3.45	4.49	3.43	4.52	2.81	3.71	2.99	3.77
12000	6.24	7.64	6.15	8.16	5.17	6.51	5.40	6.83

Positive Corona Appearance.

+	735	738	749	754
Jump	4080	4100	4100	4100
Visible	4150	4160	4110	4150

Figures for 738.00 mm. are average of three tests.

Influence of Moisture

In connection with the apparatus for the supply of dry air to the tube, an arrangement was devised whereby air could be drawn from the room through the tube. The humidity of such air was given by calculation from the readings of wet and dry bulb thermometers. Parallel sets of readings were taken from day to day of the current flowing when dry air was pumped continuously through the tube and when air from the room was sucked through before each reading. The readings and the comparative characteristics for 735 mm. pressure and relative humidity 69 per cent are shown in Fig. 10. These curves indicate a regular effect due to moisture, with a tendency for the decrease of current by humidity to be greater for negative polarity of the wire. The decrease of current by the presence of moisture is well known and these results bear out this effect.

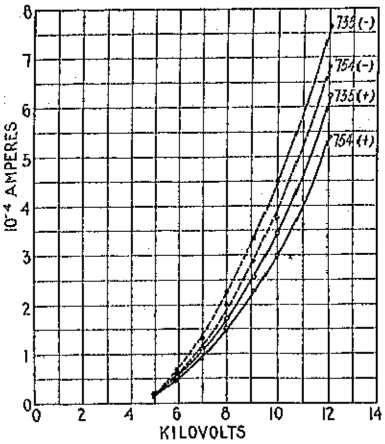

Fig. 9—Characteristic as Influenced by Pressure

No. 40 B. & S. copper wire, 0.077 mm. diameter; tube 4.45 cm. diameter, 25 cm. long; dry air at 25 deg. cent. forced through tube.

To determine whether the presence of moisture in the air has an effect upon the critical voltage, a test was run as follows, under a pressure of 736 mm. and humidity 68.5 per cent:

Air was sucked through the tube from the room and the voltage was noted at which the initial jump of the galvanometer occurred for wire positive. Then the positive glow voltage was determined and next the negative glow voltage. Then dry air was pumped through the tube and the same measurements were taken. An average of two sets of readings on the uncalibrated low scale of the Kelvin voltmeter gave the results:

	Wet Air	Dry Air
Positive critical voltage......	4300	4190
Positive glow voltage........	4350	4260
Negative glow voltage.......	4275	4370

The effect of moisture is then to raise somewhat the starting point of the positive corona and act in the opposite way for the opposite polarity.

With wire negative and moist air in the tube, the discharge begins from dim spots and the discharge is of no clearly defined nature, being a mixture of sections of continuous glow and bright spots, these spots being immobile. The discharge begins quite differently for the same polarity and dry air. As the voltage is increased, suddenly a bright spot will appear. Then for increasing voltage a number of spots appear and they are regularly spaced, increasing in number with the voltage. These brushes are in continual movement back and forth.

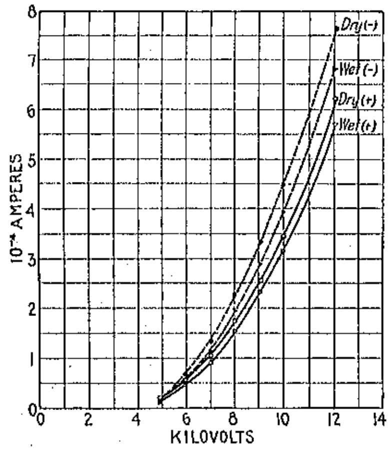

FIG. 10—CHARACTERISTIC AS INFLUENCED BY HUMIDITY

No. 40 B. & S. copper wire, 0.077 mm. diameter; tube 4.45 cm. diameter, 25 cm. long; dry air forced through tube and afterwards air from room drawn through; temperature 25 deg. cent.; humidity 60 per cent; pressure 735 mm.

The effect of moisture on the appearance of the negative discharge was shown by the following experiment:

The tube was filled with moist air and a voltage somewhat above the critical value was impressed. A mixed discharge resulted as described above. Then a current of dry air was started through the tube and little by little the discharge cleared up and resolved itself into a line of uniformly spaced brushes which were in continual agitation. If moist air were again admitted, the discharge resumed its former character.

With moist air in the tube and a fairly high potential difference, the wire vibrates circularly for both polarities, describing a torpedo-like figure of revolution. The filling of the tube with dry air diminishes considerably the amplitude of the vibration for wire positive and stops the vibration entirely for wire negative.

INFLUENCE OF TEMPERATURE

The influence of temperature upon the current for a No. 36 wire in a closed tube under a pressure of 760 mm. was determined for the range from 15 deg. to 25 deg. cent. and the results appear in Fig. 11. The lower temperature was obtained by placing cloths wet with alcohol upon the tube and directing a stream of air from a fan upon it. The curves indicate that this difference of temperature makes far more difference in the current for wire negative than for wire positive, both currents showing an increase for increasing temperature, as might be expected.

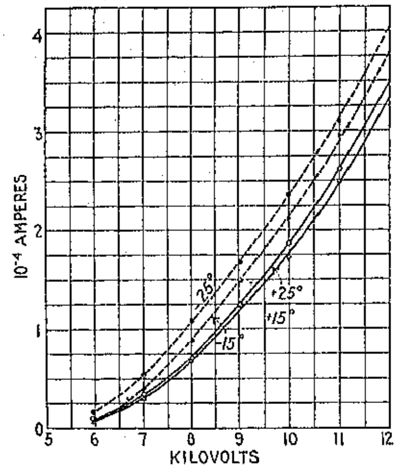

FIG. 11—CHARACTERISTIC AS INFLUENCED BY TEMPERATURE

No. 36 B. & S. copper wire, diameter 0.135 mm.; tube 4.45 cm. diameter, 25 cm. long; tube closed; dry air in tube under 700 mm. pressure.

MATERIAL OF WIRE

An attempt was made to determine the effect of the character of the surface and the material of the wire in the following way. A characteristic curve was obtained for a bright new steel mandolin " E " string in a tube open to the air. Then the wire was dipped into a solution of copper sulphate long enough to acquire a smooth coating of copper and another characteristic was obtained. Then this wire was amalgamated and another test run. A piece of the same wire was dipped into nitric acid long enough to roughen it without appreciably decreasing its diameter and a test was run on it. Small differences were found to exist in the characteristics, but these differences were accountable for by the changes in humidity and pressure during the time of running the series of tests. It was noticed that originally polished copper wires became rough on the surface through the action of the corona.

A strong electromagnet was arranged with its poles in close proximity to a tube containing a wire on which there was corona and no effect upon the current or the appearance of the discharge could be detected, either for discharges at atmospheric pressure or at reduced pressures.

COMPARISON WITH PREVIOUS INVESTIGATIONS

The starting point of the corona, and the current, depend on the radius of the wire, the nature, temperature, pressure and humidity of the air. The corona changes the chemical constitution of the air, hence there is great difficulty in formulating the laws. But for the beginning of the corona and relatively large radii Peek and Whitehead have found very neat laws expressed by the formula*

$$E = 31\,\delta\left[1 + \frac{0.308}{\sqrt{\delta R}}\right]$$

$$\delta = \frac{3.92\,p}{273 + t}$$

E is the critical electrical intensity at the surface of the wire, R the radius in cm., p the pressure in cm. of Hg. and t the temperature in degrees centigrade. In Table VI the critical electrical intensity has been calculated by means of this formula and the agreement between the calculated and the average electrical intensity or the negative value is quite satisfactory as far down as 5.32 cm. of mercury, while below this pressure discrepancies are noticeable.

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*J. B. Whitehead, *The Electric Strength of Air.* TRANS. of A.I.E.E. Vol. XXXII, 1913, p. 1317.

According to Whitehead the electrical intensity E is independent of moisture content, and the current of the corona decreases by the presence of moisture. This latter statement agrees with our observations, but for the fine wires used in this investigation moisture also affects the starting point of the corona.

PRESSURE DUE TO IONIZATION

During the first set of experiments to determine the influence of the pressure upon the coronal current for pressures around atmospheric it was noticed that when the potential difference was applied the manometer connected to give the pressure inside of the tube showed a sudden increase of pressure. This sudden increase was most noticeable for the highest pressure and amounted to a centimeter or more. Since it was desired to keep the pressure in the tube constant a carboy was connected to the tube to act as a reservoir of large capacity and prevent the increase of pressure from reaching any noticeable value.

To investigate the connection between this increase of pressure and the potential difference impressed, a sensitive U-tube open manometer was constructed. The manometer had a bore of 2.8 mm. and contained a light mineral oil of specific gravity 0.859. It was connected to the tube, the pressure in the tube was adjusted to atmospheric, the tube was sealed up and the sudden increase of the pressure was noted for voltages from those necessary to produce the corona up to those causing the maximum jump the manometer would permit without forcing the oil out. The increases were noted for both polarities of the wire. Table VIII contains data relative to the size of the wire and tube, the readings observed and the increases of pressures reduced to terms of millimeters of mercury. Fig. 12 shows the increase of pressure plotted against potential difference.

For the positive polarity of the wire, there was no appreciable increase of the pressure until the corona appeared. When the wire was negative, the presence of a small brush or two caused the level of the columns to differ appreciably before the general discharge appeared along the wire.

The jump for wire negative was greater than for wire positive for the greater part of the range of voltage and it will be seen that the general shape of the curves is the same as that of the characteristic curves for the same size of wire as given in Fig. 11. Furthermore, by comparing the numerical values of the currents and increases of pressure for like voltages it will be found that

TABLE VIII.

PRESSURE DUE TO IONIZATION

No. 36 B. & S. wire. Tube 4.45 cm. internal diameter, 25 cm. long, volume 388 cu. cm. Dry air in tube, pressure 744.0 mm., temp. 26 deg. cent.
Manometer bore 2.8 mm., containing mineral oil of 0.859 specific gravity.

Wire Positive					Wire Negative				
Potential difference	Manometer—cm. Left	Right	Diff.	mm. of mercury	Potential difference	Manometer—cm. Left	Right	Diff.	mm. of mercury
5340	Jump barely visible.			0.000	4800	Jump barely visible			0.00
6180	12.22	13.30	1.08	0.682	6180	12.20	13.25	1.05	0.664
6680	12.19	13.59	1.40	0.885	6700	11.98	13.50	1.52	0.96
7080	11.72	13.82	2.10	1.33	7100	11.70	13.75	2.05	1.30
7440	11.48	14.10	2.62	1.66	7500	11.40	14.08	2.68	1.70
7820	11.00	14.56	3.56	2.25	7850	11.05	14.40	3.35	2.12
8200	10.80	14.79	3.99	2.52	8220	10.70	14.80	4.10	2.59
8620	10.36	15.20	4.84	3.06	8600	10.40	15.10	4.70	2.97
9200	9.75	15.80	6.05	3.83	8860	9.92	15.60	5.68	3.59
9800	9.0	16.5	7.5	4.74	9400	9.3	16.2	6.9	4.36
10400	8.3	17.3	9.0	5.69	10500	7.6	17.8	10.2	6.45
10840	7.4	18.1	10.7	6.76	11000	6.8	18.5	11.7	7.39
11300	6.6	18.8	12.2	7.71	11460	5.9	19.4	13.5	8.53
12200	4.8	20.3	15.5	9.80	11940	4.5	20.7	16.2	10.2
12900	3.3	22.1	18.8	11.9	12640	2.5	22.3	19.8	12.5
13840	1.1	24.3	23.2	14.7	13520	0.4	24.2	23.8	15.0
14200	0.2	25.2	25.0	15.5					

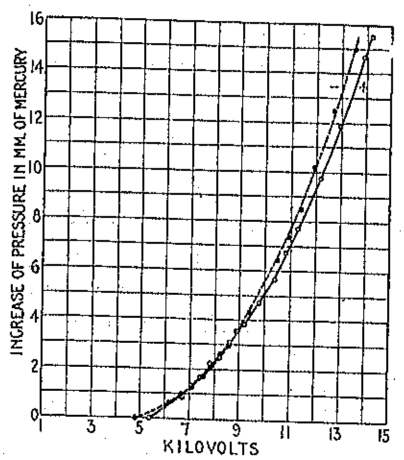


FIG. 12—INCREASE OF PRESSURE DUE TO IONIZATION

No. 36 B. & S. copper wire, diameter 0.135 mm.; tube 4.45 cm. diameter, 25 cm. long. Curves show sudden increase of pressure in closed tube when potential difference is applied. Dry air, pressure 744 mm.

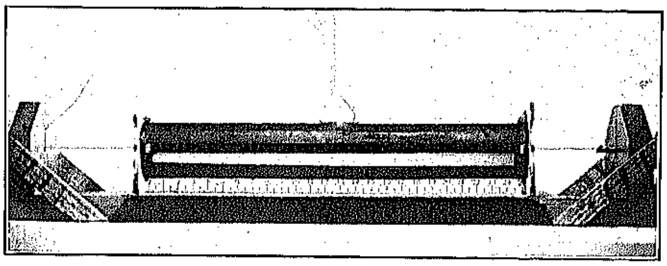
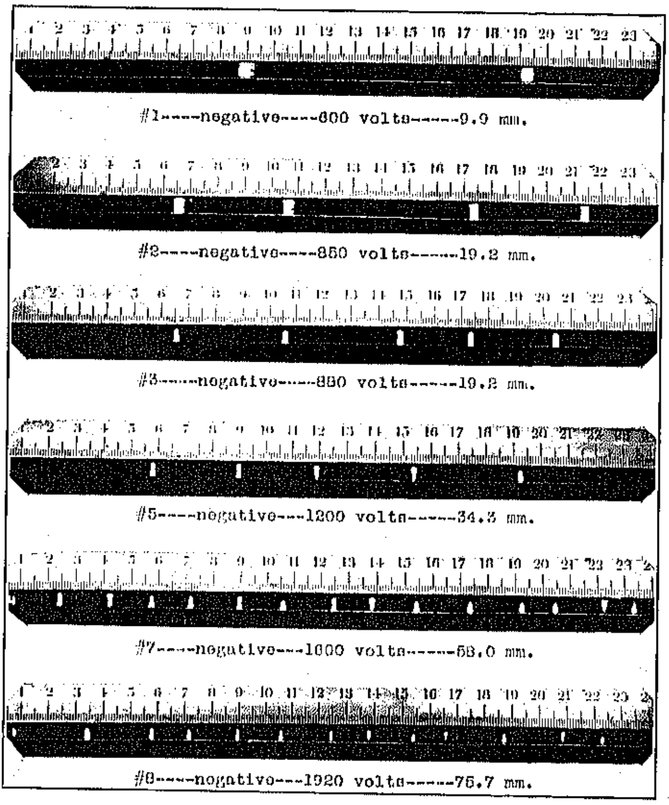


FIG. 13—TUBE USED FOR PHOTOGRAPHS [FARWELL]

B. & S. wire, diameter 0.20 mm.; tube 3.5 cm. diameter, 25 cm. long; with longitudinal slit 0.6 cm. wide.



#1----negative----600 volts-----9.9 mm.

#2----negative----850 volts-----19.2 mm.

#3----negative----850 volts-----19.2 mm.

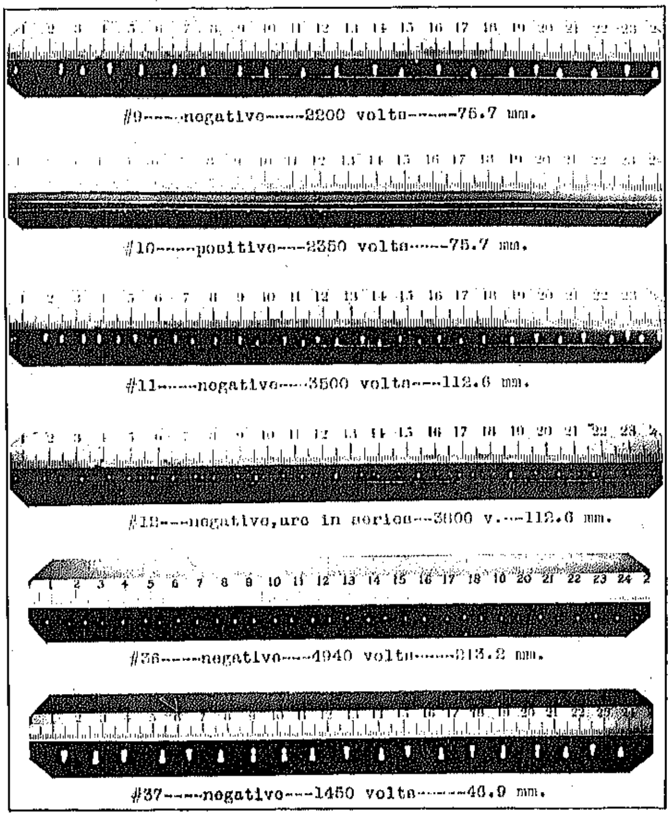
#5----negative---1200 volts-----34.3 mm.

#7----negative---1600 volts-----53.0 mm.

#8----negative---1920 volts-----75.7 mm.

Series No. 1—Pressure in tube and potential difference varied. [FARWELL]

FIG. 14—CHANGES IN NATURE OF ISOLATED BRUSH DISCHARGE WITH POTENTIAL DIFFERENCE AND PRESSURE



#9-----negative------2200 volts------76.7 mm.

#10-----positive----2350 volts------75.7 mm.

#11------negative-----3500 volts----112.6 mm.

#12----negative,arc in series---3800 v.---112.6 mm.

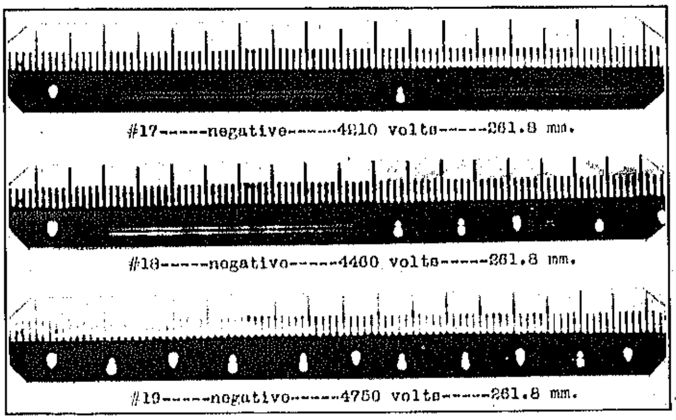
#36------negative-----4940 volts------213.2 mm.

#37-----negative----1450 volts-------40.9 mm.

[FARWELL]

Series No. 1 (continued)—Pressure in tube and potential difference varied.

FIG. 15—VARIOUS FORMS OF DISCHARGE AT REDUCED PRESSURES



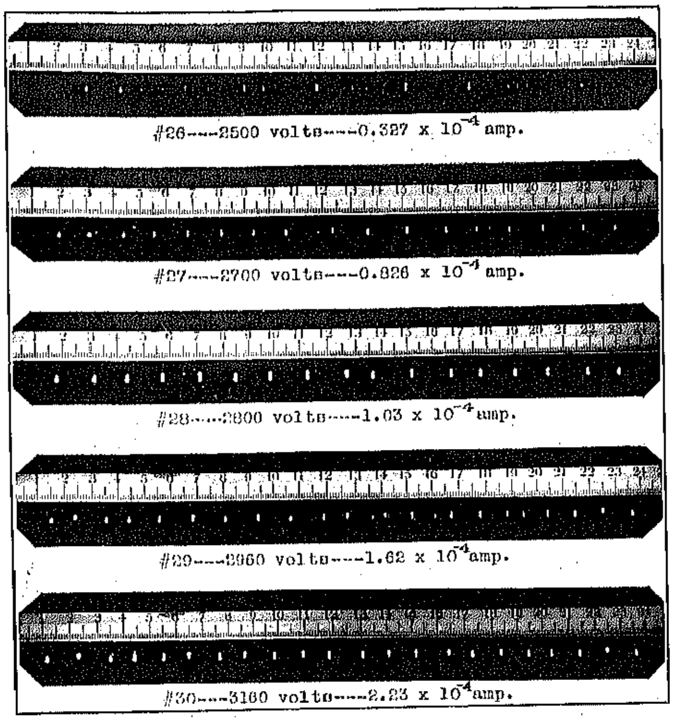
#17------negative-------4210 volts------261.8 mm.

#18------negative------4460 volts------261.8 mm.

#19------negative------4750 volts------261.8 mm.

Series No. 3—Wire negative—pressure constant. [FARWELL]

FIG. 16—EVOLUTION OF NEGATIVE ISOLATED BRUSH DISCHARGE FROM CONTINUOUS GLOW



#26---2500 volts---0.327 x 10^{-4} amp.

#27---2700 volts---0.826 x 10^{-4} amp.

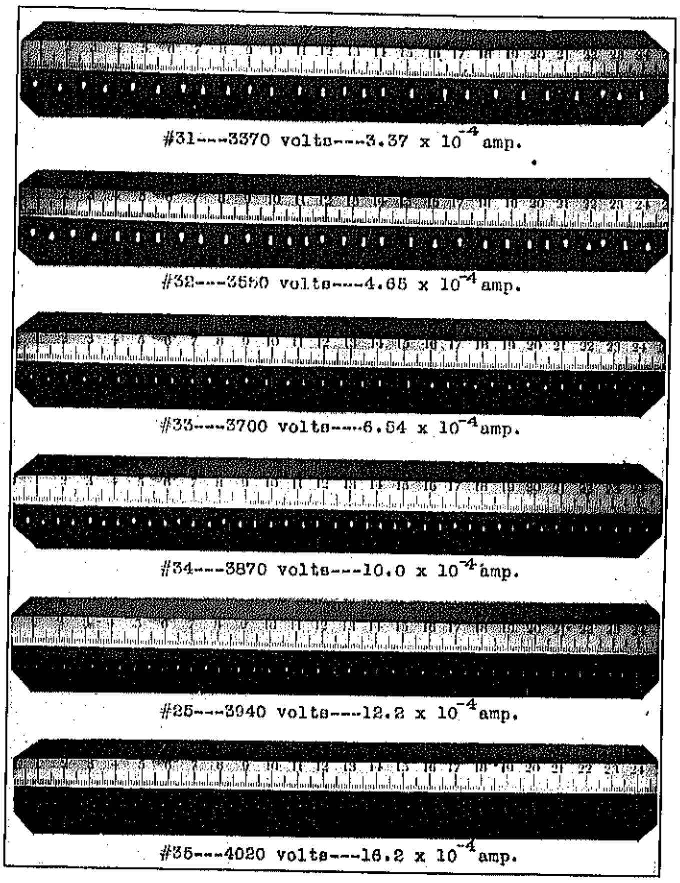
#28---2800 volts---1.03 x 10^{-4} amp.

#29---2960 volts---1.62 x 10^{-4} amp.

#30---3160 volts---2.23 x 10^{-4} amp.

Series No. 5—Wire negative—pressure constant. [FARWELL.]

FIG. 17—VARIATION OF NUMBER OF BRUSHES WITH POTENTIAL DIFFERENCE—GLOW VOLTAGE 2440



#31---3370 volts---3.37 x 10^{-4} amp.

#32---3550 volts---4.65 x 10^{-4} amp.

#33---3700 volts---6.54 x 10^{-4} amp.

#34---3870 volts---10.0 x 10^{-4} amp.

#25---3940 volts---12.2 x 10^{-4} amp.

#35---4020 volts---16.2 x 10^{-4} amp.

[FARWELL]

Series No. 5 (continued)—Wire negative—pressure constant at 119.6 mm.

FIG. 18—VARIATION OF NUMBER OF BRUSHES WITH POTENTIAL DIFFERENCE

they are proportional. This shows that the increase is an ionization phenomenon, for if the sudden increase were due to the heating effect of the current we would expect the increases to vary as the square of the currents instead of the first power.

The theory of ionization would lead one to expect such a jump when the gas is suddenly ionized; some particles in the gas would be split up by collisions and each of the constituent parts would act as a separate molecule as far as its contribution to the total pressure is concerned.

This ionization pressure might serve as a principle upon which to build a high-tension voltmeter, for if such a tube were once calibrated, the indications of the manometer would give a measure of the potential difference impressed.

DISCONTINUOUS BRUSH DISCHARGE

As already mentioned, at low pressure and negative polarity of the wire, the discharge took the form of isolated beads or brushes disposed with approximate regularity along the wire. In order to be able to see the wire broadside a glass tube was lined with a piece of sheet brass of such a width that a longitudinal slit was left along the tube, thus permitting inspection of the discharge along the central wire. The glass tube was closed at the ends by glass plates with central holes drilled through them. The wire passed through these holes and could be tightly stretched by means of a thumbscrew. The dimensions of the apparatus are given in the illustration, Fig. 13. This picture shows the branch tube through which the air could be exhausted and a wire along this tube connecting with the brass sheath. The holes around the wires where they passed through the glass plates were stopped by means of soft wax, the tube was exhausted and then filled with dry air by admitting air from the room through the drying apparatus mentioned previously. Then various forms of discharge were produced and photographs taken of them.

Series 1, Figs. 14 and 15, was taken to give an idea of the development of the discontinuous discharge from a few intensely bright beads to a series of small brushes spaced with considerable regularity along the wire. For the lowest pressures the beads consist of a bright cylindrical core along the wire, which core is surrounded by a narrow dark space, enveloped in turn by a purple glow of relatively large diameter. For increasing pressure the central core contracts to a point and the discharge, instead of surrounding the wire to form a bead, starts from this bright point and spreads out fan-like in a plane at right angles to the wire. For still higher pressures the fan seems to shut up and finally degenerates to a small brush. For all of the illustrations in Series 1, except No. 36 and No. 37, the wire was not stretched tightly and therefore the regularity of spacing of the brushes is not very great. The two photographs from which these illustrations were made were taken with the wire tightly stretched, and the regularity of spacing is apparent. No. 10 shows the typical uniform positive glow. No. 12 shows the effect upon the brush discharge of inserting an arc in series with the tube.

Series 3, Fig. 16, shows the evolution of the isolated brush form

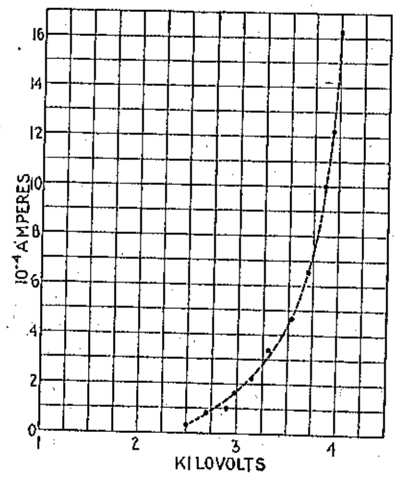


FIG. 19—NEGATIVE CHARACTERISTIC

No. 30 B. & S. copper wire, 0.20 mm. diameter; slit tube 3.5 cm. diameter, 25 cm. long; pressure in tube 119.3 mm.

of negative discharge from a continuous glow. For a potential difference just above the critical value, the negative wire was enveloped by a more or less hazy continuous discharge. Keeping the pressure in the tube constant and raising the voltage slightly causes some of the glow to turn into brushes, and with increasing voltage all of the glow is converted into the uniformly spaced form of brush discharge. Sometimes conditions can be arranged so that the brushes appear one after another with apparently no change in the conditions.

Series 5, Figs. 17 and 18, was taken to find, if possible, some definite relation between the number of brushes and the potential difference for a given pressure in the tube. The increase of the number of brushes with the voltage and the regularity of spacing of the brushes is apparent. Photographs were taken at voltages where the distribution of brushes was most regular. For the highest voltages, the brushes were in constant movement back and forth along a short path, and to secure a good picture it was necessary to make the time of exposure quite short.

Fig. 19 is the characteristic curve for the currents and voltages employed in Series 5. This graph shows the rate of increase of current with voltage to be very great at the highest voltages employed.

Fig. 20 shows the number of brushes as a function of the potential difference. In some of the photographs some of the brushes were seen to be smaller than the rest and for the plotting of the graph the estimated equivalent number of full-sized brushes was taken. Evidently the number of brushes is some well-defined function of the potential difference. Between the voltages at which the arrangement of brushes was most regular, there seemed to be a transition period in which there were many little brushes in addition to the larger ones. An increase of voltage would then produce a set of full-sized brushes.

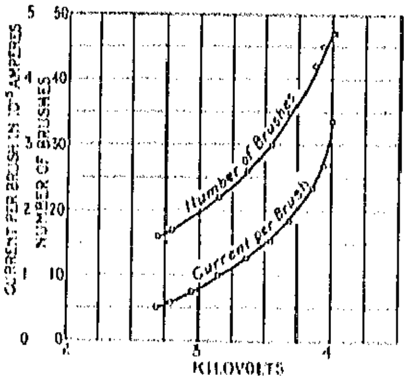


FIG. 20—NUMBER OF BRUSHES AND CURRENT PER BRUSH AS FUNCTION OF POTENTIAL DIFFERENCE

No. 30 B. & S. wire in slit tube; pressure 110.3 mm.; wire negative.

The lower curve of Fig. 20 gives the variation of the current per brush on the assumption that the total current is carried by the brushes.

EFFECT OF SHORT ARC UPON DISCHARGES

Nature of the Phenomenon. Series No. 2, Fig. 21, shows the effect of a short arc in series with the tube upon the character of the positive and negative discharges for a constant pressure in the tube and an approximately constant difference of potential.

The typical quiet bluish positive discharge shown in No. 13 is changed to No. 14, which is more brilliant, of a purple tinge and greater in diameter. In addition its boundaries seem more ragged.

The typical discontinuous negative discharge has its character changed most markedly by the introduction of the arc. No. 16 shows the changed discharge; it seems to be made up of two effects superimposed upon each other. The arc evidently sets up high-frequency oscillations in the circuit and an alternating effect is superimposed on the direct-current phenomenon. To test whether this theory was correct, the following experiment was tried:

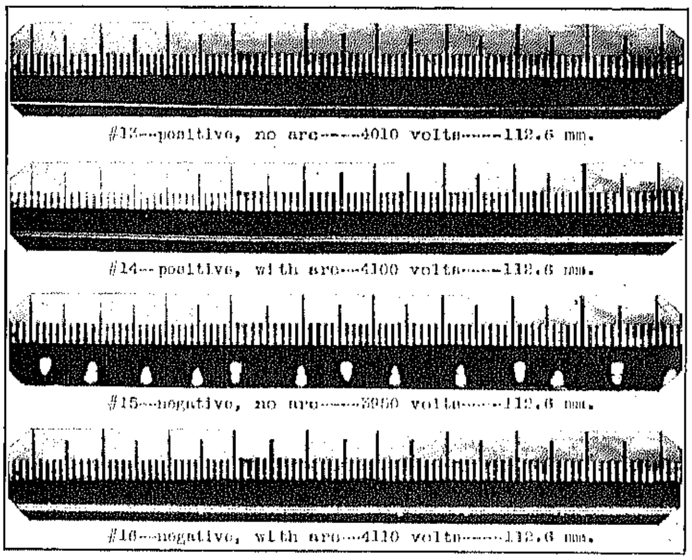
A two-mf. condenser was connected in parallel with the tube, and with the arc in circuit, a potential difference was impressed upon the tube of a value high enough to give corona. The appearance was then as though there were no arc in the circuit. The high-frequency component of the current prefers rather to take the path through the condenser than to go across the air gap.

It took an appreciable time for the condenser to become fully charged and during this time occurred the evolution of the brush discharge from the continuous glow in the manner mentioned above, except that the time of the process was prolonged.

Upon disconnecting the charged apparatus from the source of potential, the discharge through the tube persisted for some seconds, due to the discharge of the condenser through it. As the voltage of the condenser fell, the number of the brushes became less and their brightness diminished until they vanished. During this discharge, the brushes maintained quite a regular arrangement.

By assuming fair values for the electrical constants of this discharge circuit, it is easy to calculate that the discharge of the condenser must be of the continuous type. This being the case, it is evident that the negative discontinuous discharge must be essentially a direct-current phenomenon.

It should be remarked that the values of current given for the cases where an arc is in circuit represent only the continuous components, since the galvanometer deflection is unaffected by the alternating components. There is hardly another phenomenon which shows so directly the difference between positive and negative electricity as the foregoing illustrations.



#13—positive, no arc——4010 volts——112.6 mm.

#14—positive, with arc—4100 volts——112.6 mm.

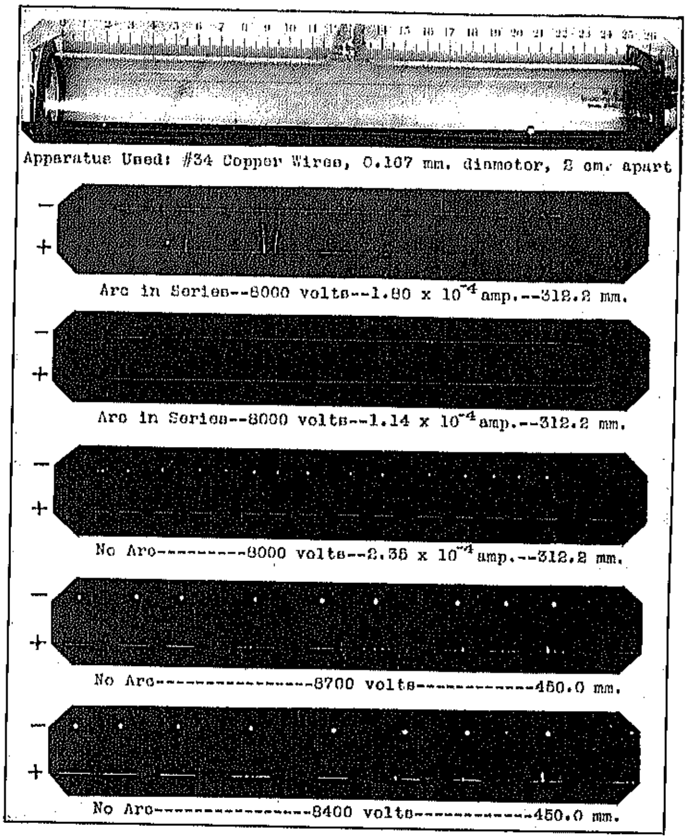
#15—negative, no arc——3950 volts——112.6 mm.

#16—negative, with arc—4110 volts——112.6 mm.

Series No. 2. [FARWELL]

FIG. 21—EFFECT OF SHORT ARC IN SERIES ON NATURE OF DISCHARGES

No. 30 B. & S. wire in slit tube; pressure constant at 112.6 mm.


Apparatus Used: #34 Copper Wires, 0.107 mm. diameter, 2 cm. apart
—
+
Arc in Series--8000 volts--1.80 x 10-4 amp.--312.2 mm.
—
+
Arc in Series--8000 volts--1.14 x 10-4 amp.--312.2 mm.
—
+
No Arc----------8000 volts--2.35 x 10-4 amp.--312.2 mm.
—
+
No Arc-----------------8700 volts-------------450.0 mm.
—
+
No Arc-----------------8400 volts-------------450.0 mm.

Series No. 6. [FARWELL]

FIG. 22—TWO PARALLEL WIRES—REDUCED PRESSURE

Nevertheless the question may be raised as to whether the isolated brush form of discharge may not be due to oscillations in the circuit. In order to make it clear that this is essentially a direct-current phenomenon, there follow some experiments and arguments which support this view.

The appearance of the brushes and the current indicated by the galvanometer are constant for a given voltage, no matter what combination of machines is used as the source of potential. One of the sets may be used and the appearance of the spots and the voltage and current noted. Then if the other set be used to give the same voltage with a different number and speed of machines, the same results are obtained. If there were oscillations set up perhaps by sparking at the brushes, we would not expect this agreement.

Mention has been made before of the effect of the introduction of a condenser in parallel with the tube. To test whether the current sent through the tube by the condenser in discharging was direct or oscillatory, another experiment was performed. The condenser was connected across the positive and negative busbars to which the generating apparatus was connected through the water resistance. Then a switch connecting the machines to the busbars was closed, as was also a switch leading to the tube. The deflection of the galvanometer was noted and the appearance of the brushes. Then the generator switch was opened and the condenser discharged through the tube and the galvanometer. After the switch was opened, the galvanometer deflection gradually decreased, the rate of the decrease being slower and slower as the discharge proceeded. The opening of the switch caused no immediate change in the brushes, only the gradual change already noted. That the discharge of the condenser must be continuous is shown by the deflection of the galvanometer and it can be further proved by a rough calculation. Assuming the resistance of the cylindrical field as given by E/I and taking a set of values of E and I for the comparatively low pressures at which the brushes are best formed, we obtain $R = 1.83 \times 10^6$ ohms. Assuming the very large value of 0.1 henry for the inductance of the circuit, and the approximate value of 2 mf. for the capacity, we find that R is about 4.1×10^4 times as great as $\sqrt{4L/C}$ and hence it is clear that the condenser discharge must be of the continuous type.

By running wires from the terminals of an induction coil to the central wire and the tube and then adjusting the discharge points on the coil to such a distance that a silent discharge took place between them, it was possible to obtain an almost uniform hazy glow along the wire. But no effect could be obtained like the uniformly spaced brush discharge.

It is well known that an arc is the source of electrical oscillations and it has been shown by a previous figure that a short arc in series with the tube disturbs the brushes due to the direct current by the superposition of an alternating-current effect, so that the glow becomes more or less uniform and the difference in the appearance of the glow for different polarities becomes much less. So the introduction of an oscillatory current acts to suppress the isolated brush form of discharge and not to cause it.

It should be stated here that Peek* by a stroboscopic method has also observed "more or less evenly spaced beads" on the negative wire when there was corona between parallel wires caused by an alternating difference of potential of 80,000 volts at atmospheric pressure. The wires used by Peek were 0.168 cm. in diameter, spaced 12.7 cm. apart.

CORONA BETWEEN PARALLEL WIRES

Phenomena at Reduced Pressures. Two No. 34 wires, 0.167 mm. in diameter, were arranged parallel and two centimeters apart inside of a glass tube as shown in Fig. 22 and photographs were taken of the discharge between them at reduced pressures. The three lower illustrations of Fig. 22 show the typical isolated brush discharge on the negative wire with corresponding luminous section of the positive wire. The negative brushes had a brilliant nucleus with a fainter glow spreading out from it. For lower pressures than those for which the photographs were taken, the discharge became more brilliant; the brushes spread farther apart and increased in size. Each section of positive glow was usually of uniform brilliance. But for comparatively low pressures and high voltage, these positive sections became somewhat discontinuous, bright spots being mixed in with the uniform glow.

The introduction of a short arc in series made a marked change in the nature of the discharge. Both wires were more or less completely covered with a nearly uniform glow and there was no longer any marked difference between positive and negative. The brilliancy of the discharge depended upon the fatness of the spark. With the arc in series, low pressures and a relatively high voltage, the discharge between the wires resembled a sheet of luminuous rain. An intermediate effect showed bluish streamers between the wires.

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*TRANS. A. I. E. E., 1912, Vol. XXXI, p. 1089, and Plate LVII.

It should be remarked that the values of current given for the cases where an arc was used are only the continuous components of the current.

Phenomena at Atmospheric Pressures. Two No. 36 wires were stretched over hard rubber bridges so as to be parallel and three centimeters apart and a characteristic test was obtained for the discharge between them. The dimensions of the wires, the atmospheric conditions and the data for a characteristic curve are given in Table IX. A sudden increase of the deflection of the galvanometer marked the critical voltage as in the case of former tests with wires in a cylindrical field. It was noted in this test that there was a considerable current flow between the wires before there was any indication of a glow. At 10,000 volts a flickering glow along the positive wire gave the first indication of a general glow.

TABLE IX.

Two Parallel No. 36 Wires—0.135 mm. diam., 36.2 cm. long and 3.0 cm. apart.

Temperature 26.5
Relative Humidity 43.0 per cent
Barometric Pressure 749.0

Potential Difference	Deflection in mm.	Shunt Factor	Current in 10^{-4} amp.
6000	0.3	1.0	0.000015
6400	0.5	1.0	0.000025
6500	Critical	Voltage	
7000	125.0	1.0	0.00634
8000	37.0	12.832	0.0241
9000	75.0	12.832	0.0488
10000	30.0	128.32	0.195 Glow sets in
12000	198.0	128.32	1.29
14000	49.0	1283.2	3.19

$F = 5.07 \times 10^{-9}$ amp. per mm. deflection.

When the visible discharge was fairly started, it took the form of a uniform continuous glow along the positive wire and a fairly regular arrangement of brushes along the negative wire. This discharge was examined on a day when the humidity was considerably greater and it was noticed the negative discharge had lost all appearance of a regular distribution and there was more of a continuous glow effect.

It was noticed that the negative wire bowed in toward the positive and that the positive bowed away from the negative. This effect was noticed in one of the preliminary experiments with an influence machine.

When the wires were purposely made rather slack in order to intensify the effect it was found that the positive wire vibrated strongly with a circular motion and that the negative was motionless. If the polarity of the wires was reversed, the phenomenon reversed also and it was still the positive wire which vibrated.

Exploration of Field between Parallel Wires. A glass tube with a platinum contact wire projecting axially from its tip was fixed into a wood block in such a manner that when the block was moved across a board beneath and parallel to the plane of the wires, the platinum contact point moved in the plane of the wires. By means of a scale fixed across the board perpendicular to the direction of the wires, it was possible to set the contact point at any desired position between the wires. When the ground terminal of one of the electrostatic voltmeters was connected to the grounded negative wire and the high-tension terminal was connected to the contact point it was found that the voltmeter deflected when there was a current flow between the wires and the contact point was in the neighborhood of the wires. So long as there was no current flow between the wires there was no deflection.

Figs. 23 and 24 show the curves for field distribution as plotted from the data, and also the distribution of the electrostatic field between the wires as calculated from the formula for the electrostatic field on a line between the axes of parallel wires. If P denotes the point where the potential is desired, A and B the inverse points of the circular sections of the wires and q represents the charge per unit length of one wire, the potential V at the point is given by

$$V = -2q \log (AP/BP)$$

Sufficient accuracy was obtained for the purpose in hand by taking the inverse points as at the centers of the wires.

An examination of the curves for the actual distribution of the field discloses the fact that there are large anode and cathode falls of potential, the anode fall of potential being the greater for the two lower potential differences. For these also the actual field departs widely from the electrostatic. For the 12,000-volt curves the actual and electrostatic fields become more alike.

The field is distorted through ionization, because the positive ions are driven toward the negative wire and form a layer of positive electricity round about the negative wire. Hence there results a very large fall of potential around this wire. Around the positive wire there is an accumulation of negative electricity and hence there is a fall of potential here also. But the positive and negative ions are of different size and mobility, and therefore the distortion of the field about the positive wire is different from that around the negative wire.

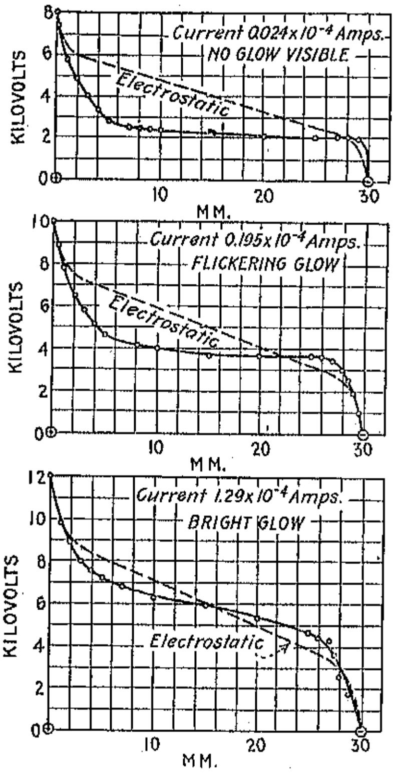


Fig. 23—Distribution of the Potential between Two Parallel Wires 0.135 mm. in Diameter, 30 mm. Apart

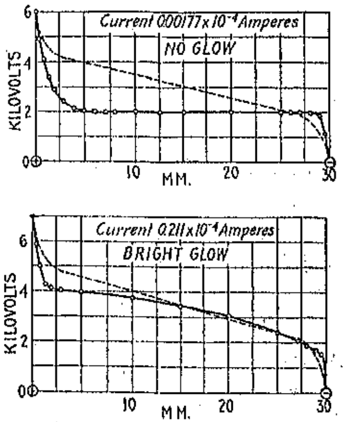


Fig. 24—Distribution of the Potential between Two Parallel Wires 0.052 mm. in Diameter, 30 mm. Apart

Notes on Test. At voltages a little above the critical voltage there is a noticeable lag of corona behind e.m.f.; in the extreme case this lag amounted to a second or so. Spots on the negative wire appear first, then the general glow, which appeared to move along the positive wire from the end leading to machines, The negative glow is by far the brightest and is inclined toward a purple, while the positive glow is blue. With the high humidity, there was no regularity in spacing of brushes, and much continuous glow on the negative.

An attempt was made to see whether after corona was formed and then the potential difference was lowered, below the critical value, the corona would persist. So far as could be determined, the corona stopped when the critical voltage was reached.

At 13,000 volts potential difference a marked electrical wind was noticed proceeding from the wires. It was strong enough to be noticed on the face when held a few inches from the wires.

At this voltage, the negative wire was vibrating with a barely perceptible movement, while the vibration of the positive wire was excessive. And also at this voltage, the negative corona seemed in more rapid movement than before; the spots were most of them oscillating back and forth. The positive wire was vibrating in a circular path.

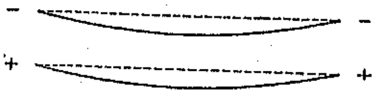


Fig. 25

With wires bowed as shown in Fig. 25, glow and increase of current appeared almost simultaneously, while with wires used in previous parallel wire test, the jump took place long before the glow appeared.

This investigation was carried out in the Laboratory of Physics at the University of Illinois under the direction of Dr. Jakob Kunz, Assistant Professor of Physics. To him, to Professor E. B. Paine of the Electrical Engineering Department and to Professor A. P. Carman of the Department of Physics, the author wishes to acknowledge his indebtedness for many helpful suggestions as to the conduct of this work.

Discussion on "The Corona Produced by Continuous Potentials" (Farwell), New York, November 13, 1914.

L. W. Chubb: The author makes certain apologies about the paper, saying it is more of technical interest than commercial value, compared with the alternating-current corona. That may be so, but I believe there is a good deal of commercial value in the study of the direct potential in connection with electrical precipitation, and our fundamental study of the electron theory and effects of ionization.

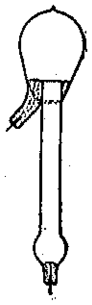
I think also the paper will stimulate a good deal of further work along this line, just as the first few papers on corona stimulated a great number of papers in the alternating-current work. There is too much in the paper to grasp or remember from reading it over once, but I think it is a very good paper for our records. I cannot read it without thinking of the various explanations which there may be for all the different phenomena he finds, some new, some not entirely new, but they have a very important connection with the work that is going on.

The bowing of the two wires in the same direction is a significant condition that has been brought out; and the concentration of the corona into beads or regularly spaced brushes on the negative seems, in a way, to correspond to the negative spots in the mercury arc or gas arc—the nature, of course, is different, but there is a similarity. The glow on the positive corresponds in a way to the luminosity around an anode that is being bombarded by the electron.

A. E. Kennelly: I ask Mr. Peek if he can throw any light on the movement of one of the wires, mentioned on the last page, where the vibration seems to be rotary as distinguished from being simply to and fro.

P. M. Lincoln: Some years ago Mr. Peek gave a formula for the loss due to corona, and that formula contained, as one of the factors, the frequency. I asked at the time why frequency should enter into a formula for the loss due to corona. It seemed to me that if it entered into this formula properly, then if we carried it down to zero frequency we would have zero loss. This paper this evening does not seem to indicate we have zero loss at zero frequency. What is the proper relation between frequency and loss? Perhaps Mr. Peek can answer that.

Max von Recklinghausen: One of the phenomena mentioned in the paper of Mr. Farwell, reminds me of a phenomenon which appears in the mercury vapor arc, which has hardly been described, namely, the appearance of luminous beads on the positive electrode. They are easiest to distinguish in the lamp shown in the sketch. We have four distinct luminosity phenomena in such a lamp, namely, (1) the disintegrating point, at the negative pole, (2) the pink negative flame, (3) the luminous column, the



most typical light phenomenon in the mercury vapor lamp, and finally (4) the pink bead phenomenon near the positive. This latter can only be seen under certain conditions of temperature and vacuum, but just this phenomenon resembles vaguely the one described by Mr. Farwell. The number of beads will change rapidly with change of conditions.

I want to say one thing regarding the corona loss. I would like it to be quite clear in our minds that economically this plays a very small part in a direct-current power transmission line. I mention this because I think it of importance that the smallest possible impediment should be thrown in the way of the development of high-tension direct-current power transmission.

L. T. Robinson: When the papers on alternating-current corona were discussed June 27, 1913, (TRANS. A. I. E. E., Vol. XXXII, p. 1810,) the fact was brought out at the meeting that the glow started a long time before the discharge started, and that we had there a rather satisfactory means, apparently, for the measurement of the high potential. But here it appears that it is even better, that is, that this critical voltage appears to be a very sharp point, and we have the commencement of the large flow on the galvanometer a long time before the glow sets in. I simply call attention to the fact that there is a definite and sharply defined effect there which I think could be put to some useful purpose.

Selby Haar: I think it will be of great interest if Mr. Farwell will give a detailed description of the generators which he uses for producing this high voltage, and also state whether they were designed under his supervision or by commercial manufacturers, and furthermore tell us why the particular sizes which were selected were chosen.

F. W. Peek, Jr.: In selecting a conductor in transmission work it is of particular importance, from the corona standpoint, to be able to predict the voltage at which loss starts. In general the operating voltage should be at or below the fair weather *disruptive critical voltage.* This paper tonight shows, as other papers have shown, that the starting voltage depends upon the maximum of the voltage wave. If the single-phase alternating critical voltage is 100 kv. effective for a sine wave, the continuous critical voltage is 141 kv. for the same conductor arrangement. The formula for the single-phase alternating effective voltage can thus be used for direct current; it is simply necessary to multiply by $\sqrt{2}$. Watson's investigations also show this. It means that in practise about 40 per cent higher continuous voltages may be used than with single-phase alternating current. Compared to three-phase alternating current, the difference is greater. (It is simply necessary to consider voltages to neutral.) This point in its favor, however, will not cause direct current to supersede alternating current in high-voltage transmission.

This one advantage for direct current is still greater in solid dielectrics, as cables. In air and oil there is very little loss until a certain definite voltage is reached. In solid dielectrics, loss starts as soon as voltage is applied and increases approximately as the square of the applied voltage—the consequent heating reduces the strength of the insulation. There is thus a gain here for direct current. It is questionable, however, how far this may be made use of, as cables generally break down by abnormal or transient voltages, which take place in either alternating-current or direct-current circuits. One other advantage is the elimination of the large capacity current.

In my 1912* paper, I gave the results of a stroboscopic study of alternating-current corona; that is, the corona was viewed through an instrument in which one could see the corona due to the positive half of the wave or due to the negative half of the wave. Photographic records were shown. It is very interesting to note that the positive corona, as shown by direct-current tests, is the same as the corona due to the positive half of the alternating-current wave; and vice versa, the same effects are observed for the corona on the negative half of the wave. If that paper is referred to, it will be seen that when the wires are very smooth and the negative half of the wave is observed, the negative corona first appears as a reddish crown around the wires. Finally, after operating a short time, the corona separates into more or less evenly spaced beads along the wires. In some cases, instead of taking the bead form it takes a spiral form. The positive corona is a bluish color and fits the wire surface very closely. With points, just the opposite effect occurs. The positive corona extends away out into a brush, whereas at the negative, there appears a red hot point. This difference is evidently due to the greater stress or higher gradient at the point, where new sources of ionization occur, perhaps from the metal itself.

Mr. Farwell shows that, except for very small wires—wires smaller than one-tenth of a millimeter—the alternating-current formulas may be applied for starting voltage, temperature, pressure, etc.

Dr. Kennelly has noted the photograph of the wire rotating due to corona. The same effect is also obtained with alternating current. In fact, by referring to my 1912 paper, it will be seen that in one case the wire is made to rotate as a whole, while in another, a node is formed in the center. For this particular case it is also a frequency meter. It shows on one half of the rotation negative corona and on the other half positive corona. It is thus rotating at the frequency of the applied voltage.

A. E. Kennelly: Does the spiraling action you mention account for it?

F. W. Peek, Jr.: I do not know. I first observed the vibration of wires due to corona several years prior to the 1912 paper. Two steel wires, each 500 feet long, were stretched between two transmission towers. The spacing was perhaps ten feet. These wires vibrated; one as a whole, and the other in three parts or with two nodes. The period was very slow, about sixty a minute. That vibration seemed to be back and forth, perhaps on account of the long span. It started when voltage in the neighborhood of 200 kv. was applied. The vibration was imperceptible when the voltage was first applied, but the amplitude gradually increased until it seemed the wires would soon come together.

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*Trans. A. I. E. E., Vol. XXXI, 1912, p. 1051.

Mr. Lincoln asks why, if there is a loss on direct current, the formula for the alternating-current loss indicates zero loss at zero frequency,
thus

$$p = a f (e - e_0)^2 \tag{1}$$

There is a loss in direct current. For the same maximum voltage the direct-current loss is perhaps in the order of one-fourth the corresponding loss at 60 cycles, but for the same effective voltages the direct-current loss is very much less. Zero frequency and direct current are not necessarily identical.

The greater part of the alternating-current loss is a "per cycle" loss. There is, however, a small constant loss. The more complete equation is

$$p = a_1 (f + k) (e - e_0)^2 \tag{2}$$

Where the frequency does not vary greatly from 60 cycles, (1) is more convenient to use in practical work; (2) is used over greater range. This equation was published more completely in my paper read before the Franklin Institute* about a year ago, and it was also given in my discussion† at the A.I.E.E. Cooperstown convention. The complete formula can be found in the *Journal* of the Franklin Institute.

I will speak briefly of another sort of corona. High-frequency corona, low-frequency corona, and direct-current corona have been discussed and are covered by the formula for alternating-current corona. There is another sort of corona—the corona transients, of single impulses. It takes energy and, therefore, a very small but definite time to start a spark or corona. For continuously applied alternating or direct-current voltages the time is, relatively, practically unlimited. When the time is limited, however, as in a transient of steep wave front, or a single impulse of short duration, much higher voltages are required to produce the same effects, or to spark the same distance, than when the time is not limited. This applies not only to air, but also to oil and solid insulations. I have made such a study and find, for instance, for a given shape of impulse reaching its maximum in $\frac{1}{4,000,000}$ second, a certain needle gap in air requires approximately double the 60-cycle voltage to spark over. For the same impulse reaching its maximum in $\frac{1}{400{,}000}$ second, the spark voltage is 25 per cent higher than the 60-cycle voltage. The time lag has in this way been accurately measured. For continuously applied alternating or direct-current voltages the initial ionization, within reasonable limits, has no effect on the corona starting voltage. For single impulses the effect may sometimes be appreciable.

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* "High-Voltage Engineering," Franklin Institute *Journal*, Dec. 1913.

† TRANS. A. I. E. E., 1913, Vol. XXXII, Part II, 1819.

S. P. Farwell: The generators used were at hand in the E. E. Department of the University of Illinois. They had been constructed without my supervision by the manufacturing company. I acknowledged in the paper the fact that F. W. Peek was the first to record beads along the negative wire in the alternating-current corona. As has been mentioned, the investigation has opened a number of new questions and further experimental and theoretical researches are in progress in the University of Illinois. The theories so far advanced cannot account for the large variety of phenomena in the corona.

Presented at the 301st Meeting of the American Institute of Electrical Engineers, New York, November 13, 1914.

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GRAPHIC METHOD FOR SPEED-TIME AND DISTANCE-TIME CURVES

BY E. C. WOODRUFF

Abstract of Paper

The paper presents a very simple method for obtaining speed-time and distance-time curves, which avoids the usual step-by-step process with its tedious calculations. The method consists of plotting certain so-called " service characteristics " upon the diagram of motor characteristics with the speed-current and traction-current curves. The time and distance increments corresponding to assumed speed increments are found by simple divider operations.

THE FOLLOWING method for obtaining speed-time and distance-time curves is a modification of that brought out by Mailloux in 1902. It is believed to possess certain merits of simplicity, speed, and directness that may make it of interest. It has proved of especial value in teaching the plotting of these curves to engineering students. Students that have struggled with the usual step-by-step process, involving rather long and tedious calculations, or with graphic methods that require the use of many sets of curves on several sheets, seem to acquire a newinterest in the subject when this method is proposed.

Briefly, the method consists in drawing on the sheet of motor characteristics besides the speed-current and traction-current curves, certain so-called " service characteristics " as shown in Fig. 1 and explained below. From these curves, time and distance increments corresponding to assumed speed increments are found by a few simple divider operations. To avoid confusion, on one of the sheets are placed the motor and service curves for a limited number of load conditions, perhaps for a motor car with and without a trailer, new sheets being readily made for wider variations in train make-up or in motor equipment.

The make-up of a sheet of curves is as follows: Motor speed-current and traction-current curves are plotted to as large a scale as possible from the records of tests. To the same scale is plotted the train resistance-speed curve, f, from Armstrong's formula, $f = W' \left\{ \frac{50}{\sqrt{W}} + 0.03\,V + 0.002\,V^2 a\,(1 + 0.1\,[N-1]) \right\}$ wherein W is the weight of the whole train in tons, while W' is the load in tons per motor. Horizontal lines are drawn, such as g, whose constant ordinates are the pounds traction required for various grades and curves for W' tons per motor. Using the upper right-hand corner as a second origin, net traction is plotted downward against time increments plotted to the left, using the same scale as for the traction-current curve. This gives one or more hyperbolas whose equations are $T_n \times \Delta\,t = \Delta\,v \times 100\,W'$, wherein T_n is net traction, $\Delta\,t$ is a time increment, W' is the tons per motor, 100 is a constant including 91.1 plus an allowance for the energy of the rotating parts, and $\Delta\,V$ is a speed increment, constant for each hyperbola. From the same corner are drawn a series of radii intercepting equal distances on the

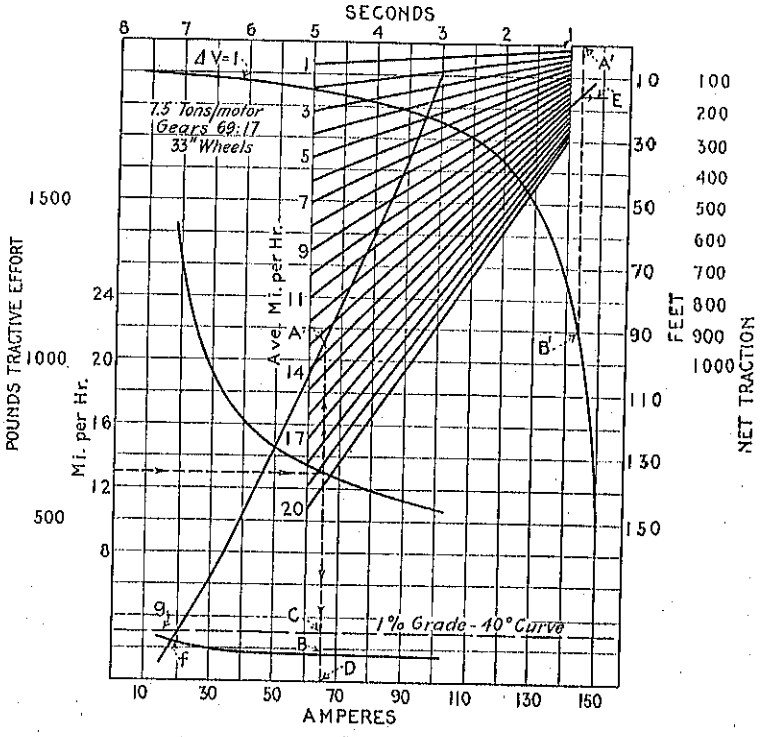

FIG. 1

vertical lines. These radii, labelled 1, 2, 3, etc., are lines of average velocity, a scale of corresponding distance increments running downward from the corner at the right. This distance scale is so selected that projection vertically from some time division, such as 5, to a radius, such as 15, and then horizontally to the distance scale, will indicate the distance travelled, in this case 110 feet, during the selected time interval at the indicated average velocity.

To use the curves on the motor sheet, Fig. 1, to obtain the car characteristics curves, Fig. 2, proceed as follows: The points on the curves of Fig. 2 that mark the end of running on control (V_1, T_1), (D_1, T_1), are found in the usual way from initial assumptions. To find the point (V_2, T_2) on the speed-time curve, assume $\Delta V_2 = (V_2 - V_1)$. On the mi-per-hr. scale at the left of the motor sheet, find the division representing the average speed, $(V_2 + V_1) \div 2$. Project horizontally to the speed-current curve and from there vertically to the traction-current curve. Set one divider point on the traction-current curve and the other on the train resistance curve, f, in the same vertical line. Increase or decrease the divider setting by the ordinates of the proper grade and curve lines if necessary. Slide one di-

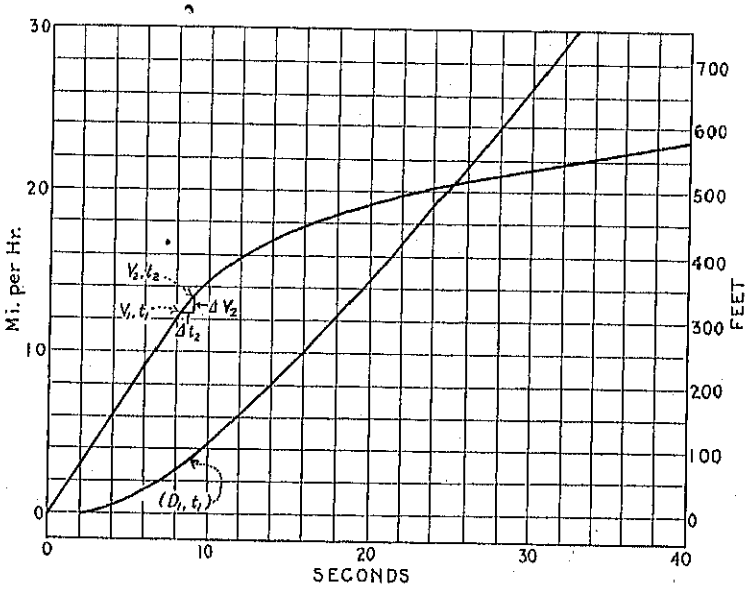

FIG. 2

vider point along the axis of time increments at the upper edge of sheet, keeping the points in the same vertical line, until the other point intersects the hyperbola whose constant was the assumed speed increment. Then the first divider point indicates the time increment, ΔT_2, and the second point on the speed-curve is determined. Drop vertically from the division ΔT_2 on the time increment scale to the radius labelled with the average speed, $(V_2 + V_1) \div 2$ and read the corresponding distance increment on the scale to the right. Proceed thus for successive points on the car curves, changing the assumed speed increment as desired to gain accuracy. For example, if the coordinates of the point (V_1, T_1) that terminates linear acceleration are 12.5 mi. per hr. and 8 sec., and 1 mi. per hr. is the first assumed speed increment, 13 mi. per hr. is the average speed and the dotted lines and arrows in Fig. 1 show the proper projections. *A-B* is the divider setting for net traction for a level tangent track at 13 mi. per hr. This would become *A-B* less *C-D* for a 1 per cent grade. *A-B* transferred to the hyperbola, $\Delta V = 1$, coincides with *A'-B'*. Then at *A'* is read 0.8 sec., and the dotted projection from *A'* shows at *E* that the distance traveled during 0.8 sec. was 15 feet.

On the motor sheet may be drawn as many train resistance, grade, and curve lines, and as many hyperbolas for different tons load per motor, as desired. It seems best, however, to limit the curves on one motor sheet to those for only two different motor loads, such as motor car with and without trailer, one- and two-car trains, etc., and to draw new sheets for widely separate classes of service. The labor involved in getting ready for the graphical work is so slight that the method saves time and trouble even when one has to plot but a single speed-time curve for a particular motor load.

DISCUSSION ON "GRAPHIC METHOD FOR SPEED-TIME AND DISTANCE-TIME CURVES" (WOODRUFF), NEW YORK, NOVEMBER 13, 1914.

Selby Haar: In looking over this paper the thought occurred to me that since it is a graphical method it is open to the objection to most graphical methods, namely, one must be very careful in the construction if the results are to be used for anything more than demonstration purposes. These methods are quite frequently used, not so much in railway work as in some other branches of the electrical industry, for obtaining guarantees to be used in contracts, and I have found that they cannot be relied upon closely enough for such purposes.

C. O. Mailloux: The subject of Prof. Woodruff's paper is of special interest to me as a pioneer in that line of technical work. I am the author of the paper (" Notes on the Plotting of Speed-Time Curves"),* published in 1902, to which reference is made in the paper under discussion.

The art of making and using speed-time curves was not old in 1902, when my paper was written, for, as stated in the paper, the first time that speed-time curves appear to have been used in the technical study of railway traction problems was in January, 1898, when they were used by Mr. S. T. Dodd and myself in an engineering study of and report upon the electrification of the Manhattan Elevated Railway, made by us at that time. The first methods of plotting the curves were crude and laborious, and much time and patience were required to obtain practical results. Very little progress was made until 1900, when the subject was taken up again by me in connection with the technical study of certain electric traction projects. The 1902 paper was written after working nearly two years in devising and applying methods of predetermination in electric traction problems. The paper, besides giving a rather comprehensive general discussion of the fundamental principles and considerations involved from the physical and analytical standpoints, sets forth different graphical and other methods which had been devised and which had been used with satisfactory results, at that time, for plotting speed-time curves and the various other curves, especially those of train power, and energy, etc., designated in the paper as " subsidiary " curves. That paper was the first publication of any kind on the subject, and it remained, for some years, the only printed reference to it. Although it was a fairly complete résumé of the subject for its time—twelve years ago—it does not and could not, of course, set forth the developments and modifications which have become known since that time. For nearly ten years after the paper was presented, I continued to use and to develop graphical and other methods of predetermination in connection with electric traction problems. Considerable publicity was given by me to these later developments in courses of lectures delivered each year during that period at different engineering schools, and also in some lectures delivered in Europe.

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*TRANS. A. I. E. E., 1902, Vol. XIX, p. 901.

Many efforts have been made to find analytical methods of predetermination which will render unnecessary the plotting of curves of train-motion, train-power, energy, etc., as a function of time or distance. The difficulties to be overcome in order to accomplish this were mentioned by me in the discussion of Mr. F. W. Carter's A. I. E. E. paper ("Predetermination in Railway Work"), in 1903. I have, several times since then, had hopes of success, which were all, however, followed by disappointments; and so these curves still have to be plotted "point by point," by the aid of graphical methods like those described in my paper or by modifications of them.

The aim of all the methods and of their modifications is the same, namely, to reduce the amount of time and work required to plot the curves. Now the part of the work that is most difficult and that requires the most time, is the determination of the proper precise point at which each portion of a curve ends and the succeeding portion begins. There are many conditions to be anticipated and to be taken into consideration as causes of incidental or of necessary variation of the speed of a train or a car in a given "run" between two stations. At one point there may be up-grades which limit the speed attainable; at other points, down-grades, which would make the speed rise too high; and at other points, curves, crossings and bridges which limit the speed allowable. In order to deal properly with all these independent variables, it is necessary to subdivide the total distance of a run between two stops into as many portions as there are changes in road and service conditions in that run. Take, by way of illustration, a simple run in which there are a few changes of conditions (Fig. 1). In the first

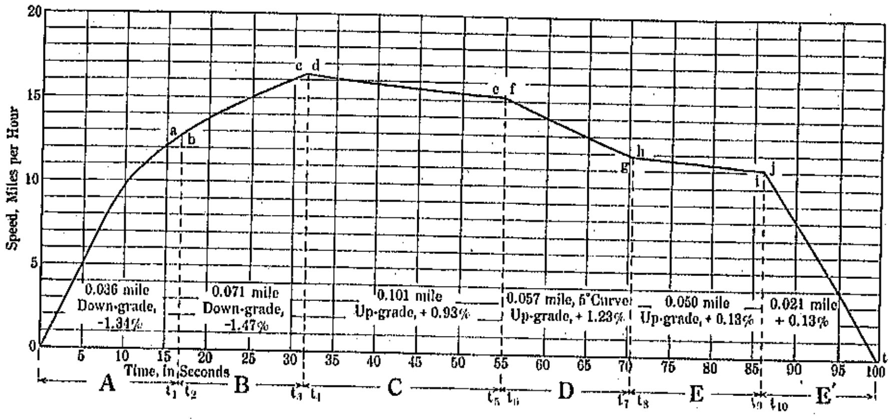


FIG. 1

portion, A, the car, as it starts, runs on a down-grade of 1.34 per cent for a distance of 0.036 mile; it then comes to a portion, B, 0.071 mile long, where the down-grade increases to 1.47 per cent, which causes the acceleration to increase instead of diminishing; after that it comes to a portion, C, 0.101 mile long, on which there is an up-grade of 0.93 per cent; on the next portion, D, 0.057 mile long, there is an up-grade of 1.23 per cent, and a curve of 5 degrees; the power is shut off and the car is allowed to coast so as to reduce the speed; on the last portion, E, 0.071 mile long, the up-grade reduces to 0.13 per cent, and the car can continue to coast with less retardation than on the previous portion, because the road is nearly level, until the point is reached, E', where the brakes must be applied to bring the car to a stop. The great difficulty, the time-consuming process, comes, as I already said, in finding where to cut these portions of a run, A, B, C, D, E, E', and in joining them properly together. The diagram, when completed, (and, by the way, I prefer the term "velocity-time diagram," or else "V-T-graph" to "speed-time curve"), must satisfy an important mathematical condition, which is, that the area corresponding to any time-interval whatever between the beginning and the end of the run must be in definite and precise proportion to the distance passed over during that time-interval. This condition is expressed symbolically by a definite time-integral, thus:

$$S = K\int_{t}^{t'} v dt$$

where S = the distance passed over in the time-interval $t-t'$
v = the velocity or speed at any instant of time, t.
K = a constant depending upon the scale of the diagram and the units of measurement employed for velocity, time, and distance.
$= \frac{1}{L}$, where L = a "scale-factor"

Now this expression is nothing more nor less than the equation of the so-called "*distance-time curve.*" The quantity indicated by this definite integral is nothing more than the area of the diagram or portion thereof comprised in the time-interval $t-t'$, whether this time-interval be that of the whole run, or of any portion of it. The distance-time graph (which may be also termed "space-time" or "S-T" graph) plays a controlling role in the construction of the V-T graph. Indeed, the V-T graph could not be made accurately, if at all, without the information which the S-T graph alone can furnish. Unfortunately, the construction of the S-T graph requires the use of some method of integration, either mechanical or graphical, and this is the very part of the whole work which almost everybody has found most difficult and tedious. The reason for saying "*almost*" everybody will be given presently. Those who sought to remove the difficulties soon realized that it was not possible to do away altogether with the distance-time graph, and that the most which they could hope to accomplish was to make a simpler and cruder form of *S-T* graph answer the purpose. The characteristic and seemingly novel feature of the paper presented this evening is an effort in this direction.

As the method of plotting described in this paper is an offspring of the ideas and methods set forth in my 1902 paper, we may begin by considering the points of resemblance and of difference between them.

We will first refer to and compare the means used for finding "points" in the *V-T* graph, for plotting that graph; and we will then compare the means for finding the distances corresponding to the different time-points in the *V-T* graph.

Those who are familiar with this subject, and with the use of the charts of "Coefficients" and of "Reciprocals," described and illustrated in my 1902 paper (Figs. 9 and 10), will easily see that the same principles are utilized in the construction of the "chart" shown in Fig. 1 of this paper. The theory of this portion of the method is the same in both cases. There are some modifications in details, which presumably were intended as improvements. Two of these deserve mention. The first one consists in drawing the curves of reciprocals (hyperbolas) on the same chart as the curves of tractive efforts corresponding to motor-power, grades, train-resistance, instead of drawing them on a separate chart, as recommended in my paper. This, it happens, is just what I did myself at first. I soon found, however, as others surely would, when working continuously for weeks and months at a time, in plotting *V-T* and other time-function graphs of train-motion, that while one may need and may have to prepare many dozens of different charts of tractive efforts and acceleration coefficients to serve for different motors, gear-ratios, voltages, train-weights, etc., and also for different service-conditions, one single set of hyperbolas ("reciprocals"), on a separate sheet, will suffice and will serve perfectly well for all the charts of coefficients, and even for several persons working on this kind of work; and that, consequently, the reproduction of the hyperbolas on every chart is a pure waste of time and effort.

In passing, I may say that the idea of "lumping in" the kinetic energy due to rotative parts by using 100 instead of 91.1 as a constant, is not to be recommended for accurate work, in view of the fact that this kinetic energy is never constant, and may have values ranging between 3 per cent and 11 per cent. It is better, in my opinion, to make the correction for rotational kinetic energy separately, and to make it correctly, for each case, especially as it can be done very easily indeed on a "Chart of Coefficients" made as shown in Fig. 9 of my paper, by the addition of one line. The second modification consists in replacing the curve of tractive effort as a function of the speed (curve *M* in Fig. 9 of my 1902 paper) by two other curves, one giving the speed, the other the tractive effort, as a function of the *current*. Now, it is precisely from these two curves (which are shown in Fig. 5 of my paper) that the curve *M* in Fig. 9 of my paper is derived; and these two curves, as used in the method described in the paper before us, serve identically the same purpose, namely, to give the *tractive effort* as a function of the *speed*. Hence, there is really no difference in the fundamental principle. The theory remains exactly the same; only, in my case, the work of obtaining from the two curves in question the values of the tractive efforts as a function of the speed is performed at the outset, once for all. The curve of these values, which is, by the way, a very important and useful curve, is plotted on the chart itself; whereas the author of the paper has to obtain the values of tractive effort from the two current-function curves for each point of the *V-T* curve, which makes the work of using the chart and the chances of error both greater. There are at least two practical objections to the innovation; first, two distances have to be measured, one horizontally, the other vertically, to obtain the value of gross tractive effort corresponding to any speed, prior to subtracting the loss due to train-resistance and up-grades, or to adding the gain due to down-grades (an operation which requires still other measurements, and, consequently, introduces more possibilities of error), whereas the curve *M* of the chart of coefficients (Fig. 9 of my paper) not only gives the desired values directly for all speeds so they can be read off without dividers, but it even enables the sum or difference of the tractive efforts in question to be read off or measured directly at one operation; second, it is not possible with the chart shown in Fig. 1 of this paper to determine at a glance, as can be done so easily by means of the chart shown in Fig. 9 of my paper, the point of zero acceleration, and, consequently, the maximum speed attainable under any and all conditions of grades and train-resistance, also to determine the acceleration or retardation which will occur on any given grades, etc., and to answer various other questions which the chart of coefficients can answer readily and accurately by the curve *M* and the curve *N* (net tractive effort) as shown in my paper. The fact is that the curves *M* and *N* give an actual graphical representation of quantities which are of immediate interest and importance, namely, the "gross" and "net" tractive efforts as a function of the speed; whereas the two curves from which the curve *M* is derived give graphical representations of functions which are not of immediate but only of remote or incidental interest. In addition to this, the use of the curves *M* and *N* makes the operation of finding the points for plotting the *V-T* graph simple and more accurate than the method represented in Fig. 1 of the paper. The practical value of the modifications just considered does not, therefore, appear to be obvious. To me it appears, on the contrary, quite doubtful.

A word of caution may be added here about taking train-resistance formulas at their " face value ", or without discount or comment. Experience has demonstrated long ago that " circumstances alter cases " very greatly in train-resistance; and that the formulas often require considerable change in form and in coefficients to make them suitable for different cases. A glance at the formulas mentioned in the paper shows readily to an experienced person that it is best suited for interurban lines running at high speeds on first-class tracks, and wholly unsuited for lighter cars or trains run at lower speeds, on city tracks. In practise it is necessary to use *several* curves of train-resistance for the same motor-equipment per car or per train. Several sets of curves of tractive efforts and train-resistance may be drawn on the same chart. I have drawn as many as eight sets on the same chart of coefficients; but, as a rule, it is not desirable to put more than two or three sets on the same chart. It is better to make new charts, which is a very simple matter when blank charts are prepared beforehand, as recommended in my paper.

The portions of the chart shown in Fig. 1, so far considered, relate to the process by which speed-time curves (or *V-T* graphs) are plotted by a " point-by-point " process. In summing up what has been accomplished in connection with this portion of the subject in the last thirteen years, I feel quite warranted in making the statement that all the methods of " point-by-point " plotting of *V-T* graphs which have proved satisfactory and practical are based upon and embody the ideas and the essential features set forth in my 1902 paper. At any rate, although I have kept in close touch with this work, I have yet to learn of a successful method which is not patterned on the lines therein suggested; and, usually, the modifications, if any were made, were not of material importance or advantage. Most of those who have done work and who have written on this subject have acknowledged the original source of the ideas and features adopted. In other cases there has been a seemingly studied silence on that score; and I have had the interesting experience of seeing my own methods, with practically no modification or disguise, explained to me by persons who had learned about them in Germany and believed that they had—in fact must have—originated there. It was a case where the label " Made in Germany " should have read " *Copied* in Germany, from the original American model ".

We come now to the operation of cutting off *V-T* graphs, or portions thereof, at the proper time-points. We find here a marked divergence in views and in methods. The methods described in my 1902 paper involve the accurate mechanical integration of the actual *V-T* graph, and the drawing of its integral-graph—the distance-time graph—which is represented by the equation to which reference was made a few moments ago. The method shown in Fig. 1 of the present paper aims to obtain the time-points of distances by a process of graphical integration of a modified and simplified *V-T* graph, in which the instantaneous velocities during a certain time-interval are replaced by an " average " velocity for that time-interval.

While this part of the work, as already stated, has been found very difficult and tedious by *almost* everybody, yet, paradoxical as it may seem, it is regarded by others, including myself, as being the easiest and most interesting part of the whole work. The explanation of this difference is simple enough. It is the difference, merely, between, on the one hand, trying to dodge or shirk the task of performing an operation of integration, and, on the other hand, making arrangements to do it very accurately while doing it easily and quickly—it amounts to a question of the facilities available for the mechanical integration of the *V-T* graph, and for drawing its integral line—the distance-time graph. Where the proper integrating facilities are available, there cannot be the least doubt that the most accurate, as well as the easiest and quickest method of finding the definite time-points which correspond to given and determinate distances in *V-T* graphs, is by drawing the integral lines of these *V-T* graphs and by making use of them in the manner set forth in my 1902 paper. All those who have done the work or who have seen it done in the proper manner by this method, understand fully why the work is both easy and interesting, and why the method is both rapid and accurate; and they also can see the drawbacks and difficulties of all methods which aim to simplify the integral-line of the *V-T* graph or to avoid drawing it.

I realized at the outset, in entering upon this work, the importance of having at hand a satisfactory integrating apparatus by whose aid integral lines could be obtained quickly and accurately. Fortunately, such an apparatus was already available in the form of an integrating instrument called the " integraph ", which, as stated in my 1902 paper, " in addition to giving the numerical results of the integration, actually shows the steps of integration graphically by drawing the so-called 'integral' line". The time required to draw, with an integraph, the integral line corresponding to any area is no greater than that required to follow with the tracing point of the instrument the outline of the diagram to be integrated. The " scale " of the integral line can be as easily varied as the "scale" of a planimeter, so that it is easy to adapt the area-units exactly to any coordinate paper, and even to make corrections for the difference in various papers due to shrinkage, humidity, etc. The integraph is in every sense an instrument of precision as well as a great time and labor saving device, of the highest value in work of this kind. In one series of predeterminations made under my direction, covering a period of about six months, one integraph saved over ten times its cost, and greatly shortened the time required for the work, besides adding very greatly to the precision of the work done. It is by the aid of this wonderful instrument that the otherwise difficult and tedious tasks are rendered easy and interesting. It is important to bear in mind that there are other integrations to be performed besides that of the *V-T* graph, for which the integraph can be also used to great advantage. As is well known, the *V-T* graph itself is, in reality, merely what might be termed the foundation and scaffolding for the structures which are of real importance and significance, namely, the "subsidiary" curves, like those of current and power input, energy, etc. Now the energy-time curve, representing kw-hours, is the integral curve of the power-time curve representing kw-input. In Fig. 5 the energy-time curve, shown on the upper part of the diagram, was drawn directly by the integraph by the integration of the kw-input curve which is shown on the lower part of the diagram. The curve was drawn in a few minutes, whereas it would have required several hours to obtain the same curve by any other process of integration, with probably much less precision. The utility of the integraph does not end here by any means. For determining, from the current-input curve, the equivalent "heating" current, or the r.m.s. value, it is a most valuable labor-saving appliance. The manner in which the integraph is employed for such predeterminations will be found described in a special paper on that subject, presented by me at the Turin Electrical Congress in 1911 (see Proceedings of Turin Electrical Congress, II, pp. 990-1016). A graduate-student who attended one of my courses of lectures and of drafting-room instruction and exercises in predeterminations by the aid of the integraph, informed me at the end of the term that he had done easily in less than two weeks more and better work than he had been able to do in about two months some time before, while employed on the same kind of work in the railway engineering department of one of the large companies. This is a fair sample of the results which indicate that the best method is the cheapest. Usually those who have this sort of work to do have enough of it to make it economical to use an integraph as a time and labor saving device, besides improving the quality and precision of the work done.

I have with me some specimens of *V-T* and other graphs that show the kind of work done by my methods with, of course, the aid of the integraph, which I consider indispensable for high-grade work. I also have some diagrams specially prepared to illustrate certain points in the comparison of different methods.

I will first show how easily the operation of cutting off and joining portions of a *V-T* graph can be performed by the aid of the integral-graphs drawn by the integraph. I will describe the process whereby the different portions (*A*, *B*, *C* . . . *E'*) of the *V-T* graph already referred to (Fig. 1) were constructed and joined together. Fig. 2 shows the details of construction for portion *A* only. Fig. 3 shows the details for all the portions.

Starting with portion *A*, the first step was to find the co-ordinates of a certain number of points for this portion of the graph. This was done by the use of charts of " coefficients " and of " reciprocals " in the manner described in my paper. The diagram of acceleration and retardation coefficients used must, of course, be that suited for the particular motor-equipment and service-conditions of the case; and it must be specially prepared when not already " in stock ". In an office where much of this work is done, the stock of graphs of acceleration and retardation coefficients is being constantly increased by additions made from time to time to meet new conditions and requirements, such as changes in type and size of motors, or in h.p. and tractive effort available per ton of train, also changes in gear-ratio, voltage, etc., and changes in train-resistance due to difference in track conditions, length and weight of train, etc. If all the charts of coefficients prepared are preserved they constitute, in time, a large assortment of charts covering a great range of conditions and requirements. As already stated, only one chart of reciprocals is necessary for any and all the charts of coefficients, provided the latter are all made to the same scale.

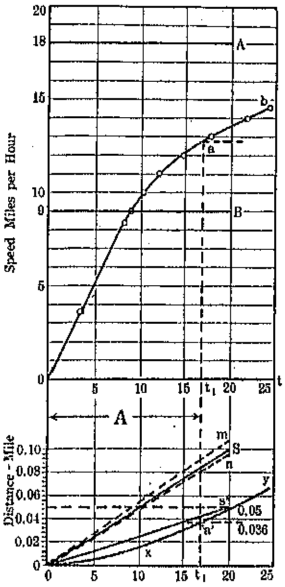


FIG. 2

Using a chart containing the proper curves of acceleration and retardation coefficients, *i.e.*, the proper curves of motor tractive efforts and train resistance as a function of the speed, and proceeding in the simple manner explained in my paper, the co-ordinates for the initial portion of a *V-T* graph are then found for portion *A*, which, as the data given on the diagrams indicate, (Figs. 1 and 3) is on a " down " grade of 1.34 per cent. While each point may be plotted from its co-ordinates as soon as these are obtained, it saves time to defer doing it until the co-ordinates for a number of points have been obtained. When several persons are employed on the same work, one may find the co-ordinates while another plots the graphs. The points for which co-ordinates were obtained in this case are indicated by small circles. The co-ordinates are determined so easily and so rapidly that there is no objection to plotting the graph considerably beyond the point at which a rough estimate indicates that the portion will end. The *V-T* graph for the portion *A* was plotted only a short distance beyond the right point *a* in Fig. 2, but a considerable distance beyond that point, *b*, in Fig. 6.

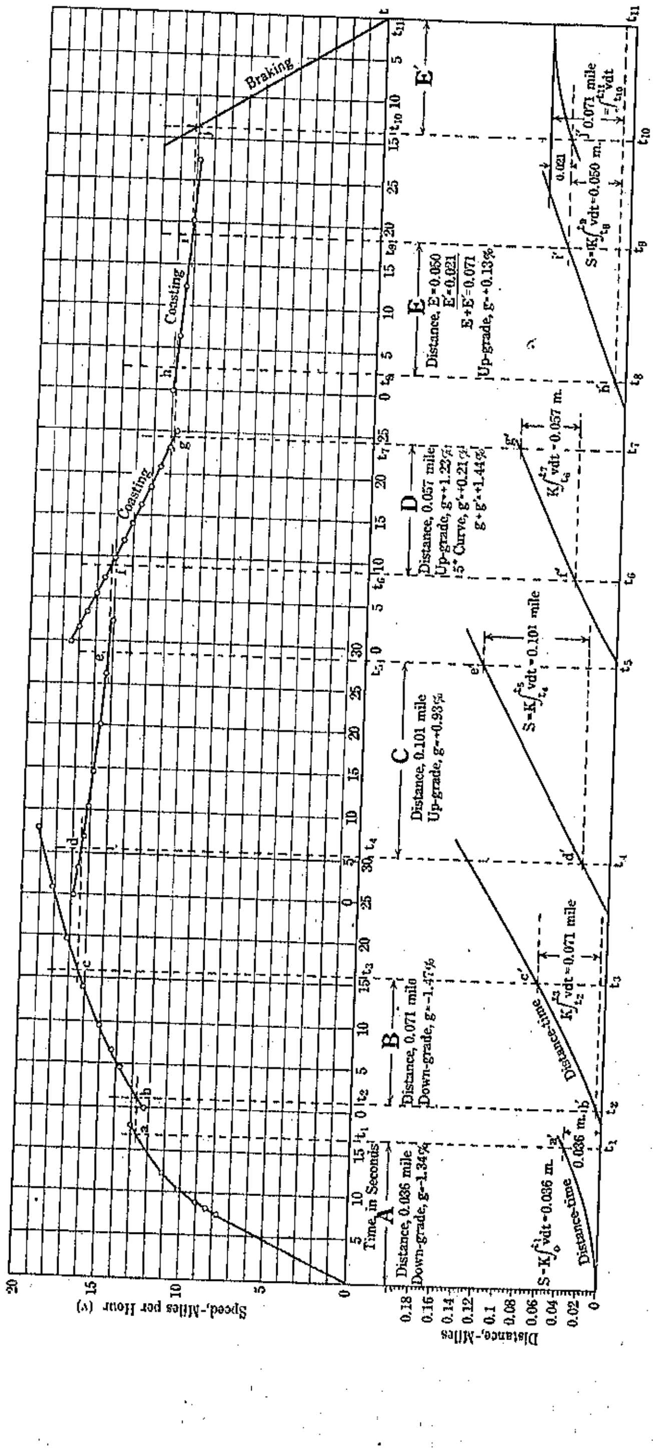

Speed-Miles per Hour (v)
Distance-Miles
Time in Seconds
Braking
Coasting
Coasting
A
Distance, 0.036 mile
Down-grade, g=-1.34%
B
Distance, 0.071 mile
Down-grade, g=-1.47%
C
Distance, 0.101 mile
Up-grade, g=+0.93%
D
Distance, 0.057 mile
Up-grade, g=+1.22%
5° Curve, g'=0.21%
g+g'=1.44%
E
Distance, E=0.050
E'=0.021
E+E'=0.071
Up-grade, g=+0.13%
E'
Distance-time
Distance-time
$S=K\int_0^{t_1} v\,dt=0.036$ m.
$K\int_{t_2}^{t_3} v\,dt=0.071$ mile
$S=K\int_{t_4}^{t_5} v\,dt=0.101$ mile
$K\int_{t_6}^{t_7} v\,dt=0.057$ m.
$S=K\int_{t_8}^{t_9} v\,dt=0.050$ m.
0.021
0.071 mile
$=\int_{t_{10}}^{t_{11}} v\,dt$
0.036 m.
a b c d e f g h i j
a' b' c' d' e' f' g' h' i' j'
t_1 t_2 t_3 t_4 t_5 t_6 t_7 t_8 t_9 t_{10} t_{11}
0 5 10 15 20
0 0.02 0.04 0.06 0.08 0.1 0.12 0.14 0.16 0.18

FIG. 3

After a portion of V-T graph of more than sufficient length has been plotted and drawn, in pencil, the next step is to find the point a, at which the portion A ends. We begin by adjusting the integraph to the desired scale, so as to obtain an integral line whose ordinate at any time-point, when measured by a scale, will give the exact distance covered, up to that point. When the same co-ordinate paper has already been used, and the scale-factor for the integraph is known, the adjustment can be made directly. When the scale-factor is not known, the proper adjustment may be obtained by drawing, a number of times, the integral curve for a certain definite area of V-T graph corresponding to an exact distance, and varying, each time, the adjustment, until an integral graph is obtained of the exact scale desired. In Figs. 2 and 3 the scale used for ordinates was 1 mi. per hr. = 0.2 in., and the scale used for abscissas was 1 sec. = 0.1 in. A distance of 1 mile corresponds to a velocity of 1 mile maintained during one hour (3600 mi-sec.), and this would correspond on the V-T graph to an area of $0.2 \times 0.1 \times 3600 =$ 72 sq. in. The same area, for a velocity of 18 mi. per hr., or an ordinate height of 3.6 in., would correspond to an abscissa value of 200 sec. or 20 in. Taking a distance of 0.1 mile and a velocity of 18 mi. per hr., the time required is 20 sec. The scale of distance adopted in Fig. 2 and 3 was 1.25 in. = 0.1 mile; hence the integraph required to be adjusted so as to draw an integral line whose ordinate at $t' = 20$ sec., is = 1.25 in. when the area integrated is exactly 7.2 sq. in. The scale-factor should therefore be $= \frac{7.2}{1.25} = 5.76$. This means that in the equation

$$S = K \int_{t}^{t'} vdt$$

when $S = 1.25$ and V and T are both expressed in inches, then $K = \frac{1}{L} = \frac{1}{5.76}$ if the co-ordinate paper used is accurately divided and requires no correction. In most cases some correction is required, as the co-ordinate paper or tracing cloth used is seldom exactly right; and the precise values of K will be either greater or smaller than the theoretical value.

In Fig. 2 the inclined right line $O\ S$ in the lower part of the diagram is the integral line or graph which was drawn by the integraph when its tracing point was moved, in the upper part of the diagram, along the lines O-18, 18-A and A-20, which represent a V-T graph of constant velocity = 18 mi. per hr., and when the scale-factor L of the instrument was exactly right for the co-ordinate paper used. The ordinate of this integral line at $t' = 20$ is exactly equal to 0.1 mile by the scale of distance. The V-T graph of constant velocity = 9 mi. per hr., gives an integral line OS' of half the slope of OS. The inclined lines Om and On show integral lines obtained instead of OS when the scale-factor, L, was respectively lower and higher than the correct value. As it only requires the movement of an adjusting screw to change the scale-factor and to draw a new integral line, the correct value of L can always be found very readily. The time required to make the adjustment is less than that required to describe it. In practise, the adjustment often remains unchanged for days and weeks at a time. After the instrument has been properly set for the paper and the scales employed, the next step is to integrate the actual *V-T* graph *Oab* (Fig. 2), and obtain its integral graph *Oxy*. Having done this, a horizontal line is drawn through the integral-graph at the ordinate height corresponding to the actual distance of portion *A* of the run, which is 0.036 mile. The abscissa of the point a', at which the horizontal line intersects the integral-line, represents the time at which portion *A* of the run ends; and a vertical line a'-a drawn through a' will cut off the *V-T* graph exactly at the end of portion *A*. The process of cutting off the portion *A* is seen more clearly in Fig. 3, in the lower portion, where only the integral-graph actually necessary, Oa', is drawn. The whole operation only requires a few moments.

The next step is to obtain the co-ordinates for a number of points for plotting the second portion *B* of the *V-T* graph. The process for obtaining the co-ordinates is substantially the same as for portion *A*. In this case the up-grade increases to 1.47 per cent, and the distance is 0.071 mile. We can start plotting the curve anywhere on the sheet, beginning with a speed that is somewhat under the speed at the end of the portion *A*. A portion of *V-T* graph is then plotted, counting time-values from the first speed-point used. The portion *B*, as shown in Fig. 3 begins with the speed of 12.3 mi. per hr., and continues until the speed of 19 mi. per hr. is attained (in about 33 seconds). After the points have been plotted, and the graph has been drawn, the integral-graph for the whole portion plotted is drawn by means of the integraph; and the operation of cutting off, from the portion plotted, the precise part and portion required for portion *B* of the *V-T* graph, can then be performed very easily. As portion *B* is a continuation of portion *A*, the speed at its beginning must be *exactly* the same as the terminal speed of portion *A*. This speed, and the starting points of portion *B* are both easily found by the very simple operation of drawing through the end of portion *A*, at "*a*," a line parallel with the axis of time, to intersect the second portion of graph at *b*. This point of intersection *b* is the proper beginning of the portion *B* of the run. From this point a vertical line drawn downward, b-b', to intersect the second integral-graph, gives the "lower limit" b' of the definite integral representing the distance-time curve for portion *B*. To obtain the "upper limit" of the integration required, a line parallel with the time-axis is drawn through the point b', and from this line as a base a vertical distance is marked off, equal, by the scale of distance, to the actual distance for portion B; and another line drawn parallel with the time-axis through the upper part of the distance just marked off, intersects the integral-graph at the point c' corresponding to the "upper limit." A vertical line c'-c, drawn upward from c', to intersect the *V-T* graph, cuts it off at the proper ending point c. The portion b-c is all that is needed for portion B of the *V-T* graph. If desired, the useful portion can now be shifted to the left, so as to bring the point b on the point a, thereby joining the portions A and B together. All that is necessary is to transfer the plotted points of portion B to the left by means of dividers to a distance equal to a-b. A new portion of graph can then be drawn, by means of these points, and the other graph being no longer necessary, can be erased. If desired, the useful portion of the integral-graph can also be shifted so as to form the continuation of Oa' from the point a'. As a matter of fact, the easiest and quickest way of making the shift is to integrate the useful portion b-c after its transfer, placing the integraph pencil or pen on the point a', so as to make the integral line start from that point. The integraph will then draw the portion B of the integral graph in the correct relation with respect to that of portion A.

Another plan is to leave the different portions of the run separated and to "assemble" them afterwards on a "tracing." This plan usually takes less time than the other.

The process of plotting, drawing, and cutting off the useful portions of *V-T* graph for portions C and D is substantially the same as for portion B. In portion C the train, though running with power, is losing speed, because it is on an up-grade. In portion D the power is cut off to reduce the speed, on account of a curve which exists on this portion of the run. In portion E the coasting continues on a nearly level track until a point is reached where the braking must begin in order to bring the train to a stop. Now the portions E and E' together represent the final portion of the run, which is 0.071 mile in length. The important point is to find out the exact time at which the braking must begin. This operation, which is usually very difficult by other methods, is rendered very easy by the use of the integraph. As the rates of retardation attainable by braking are known, the "slope" of the braking portion of the *V-T* graph is also known. This portion can be drawn "backwards" from any convenient point. The coasting curve for the earlier portion E of this part of the run is plotted "forward" in the usual way from any convenient point, and its integral-graph is drawn by the integraph. After the portion D has been properly cut off at both ends, its final point g determines the initial point h of the portion E by means of the horizontal line g-h in the manner already explained. The point h in its turn determines the point h' which is the lower limit of the useful portion of the integral-line for portions E and E' together. The upper limit is then obtained by drawing a horizontal line at the proper distance (0.071 mile) above the line through h'. Now by integrating the braking curve "backwards" from the line of upper limit, the integral-graph of the braking curve will be drawn *downwards* from this line. Any horizontal line drawn between the upper and lower limits will intersect the integral lines for portions E and E'. The distance from this line to the lower limit will correspond to the distance for portion E and the distance to the upper limit will correspond to the distance for portion E'. Now there is only one particular "level" at which this line will be correctly located; and this level is found quite easily by the aid of the two integral-graphs. We may begin by drawing a horizontal line at any level, between the two limit-lines. Through the points of intersection i, j, of this line, with the integral curves $h'i$ and $j'k$, vertical lines $i'i$ and $j'j$ are drawn to intersect the corresponding portions of the V-T graph. Now if the points intersected i, j, by these vertical lines are at the same level, so that they can be joined by a horizontal line, then the line i' j' was located at the proper level; if not, the line $i'j'$ must be changed to a higher or lower level until the points i, j, come to the same level. Usually the proper location for the line $i'j'$ is found by two or three trials. In this case the correct location makes the coasting portion, E, 0.050 mile long, and the braking portion, E', 0.021 mile long. The different portions may be "assembled" on the same sheet, by displacing or shifting their useful portions to the left in the manner explained in connection with portion B. The easiest way to "assemble" them is by the operation of "tracing" from a sheet, like that shown in Fig. 3. The "tracing" of the completed V-T graph is as shown in Fig. 1.

Although it is more natural and usually more convenient to begin the plotting of a V-T graph by the initial portion, yet it will be possible to begin the plotting at any other portion. In fact, each portion could be plotted on a separate sheet, and by a separate individual. The objection to this would be that it would be necessary to plot a much longer portion, because it would not be so easy to determine between what speed limits the "useful portion" of the V-T graph is likely to come. It is, however, often necessary to plot certain small intermediate portions of a run by themselves, and also to do some plotting backwards. The necessity for this is apt to occur for portions of a run where bridges and sharp curves occur, and where it is necessary to coast or put on the brakes in order to reduce the speed, so as to keep it below the limit allowable. A case of this kind is illustrated in Fig. 13 of my 1902 paper. It is in cases of this kind that the superiority of the method just described over all other methods becomes evident.

The run just considered is of simple character, as compared with most of the runs which are typical of actual service conditions. The conditions were arranged so as to give somewhat abrupt changes of acceleration and retardation at the points where the intermediate portions *C*, *D*, *E*, are joined together, so as to make the process of cutting off the portions more easy to illustrate. Figs. 6 and 5, reproduced from one of my lectures, show the details and the completed curves worked out in more "professional" manner, although the details are not completely given in Fig. 6. The complete *V*-*T* graph in Fig. 5 was traced from the "portions" as worked out on Fig. 6. The distance-time curve was drawn in pencil by assembling the "useful" portions as shown in Fig. 6, and the whole curve was then "checked up" by integrating the completed *V*-*T* graph in Fig. 5, and drawing the integral curve in ink by the integraph, with the result that the total error for the whole *V*-*T* graph was less than the thickness of the integral-line. This fact is mentioned as an illustration of the degree of precision obtainable with an integraph in good condition and used intelligently. The power-time (or kw-input) curve was plotted by reference to the completed *V*-*T* graph in Fig. 5 and it was then integrated by the integraph, producing the energy-time curve (kw-hr.). From this curve the energy consumption per train, per car-mile, and per ton-mile, were calculated, as given on the sheet. The operation of plotting the power-input curve is greatly facilitated by making, first, a chart which shows the power (kw.) as a function of the speed. With the aid of such a chart, the whole operation of plotting the power-input graph is performed in a short time by the use of dividers. The dividers are first set on the *V*-*T* graph to the actual velocity at a given time-point. The dividers are then transferred to the kw-velocity chart. The kw-input corresponding to that particular velocity is readily found and, being taken by the dividers, is transferred to the sheet on which the graph of kw-input is to be drawn. In some cases other velocity-functions, such as the power and energy expended in acceleration and the power and energy recovered in coasting, and also various other time-functions, like the power and energy expended in overcoming train-resistance and lost in the motors, are plotted on the same sheet with the *V*-*T* graph, and their integral-graphs are then drawn by the integraph. From these a complete analysis and segregation can be made of all the power and energy losses occurring during a run. A complete analysis of this kind, which is very simple with the integraph, has never been attempted without its aid, so far as I have been able to learn; and the simple reason is the difficulty and the great amount of work of drawing the necessary integral-graphs in any other way than by an integraph. These details, which are beyond the scope of the present discussion, are only mentioned here to show the far-reaching character of the services which the integraph can render as an instrument of precision and also as a device for saving time and labor, in connection with work of this kind.

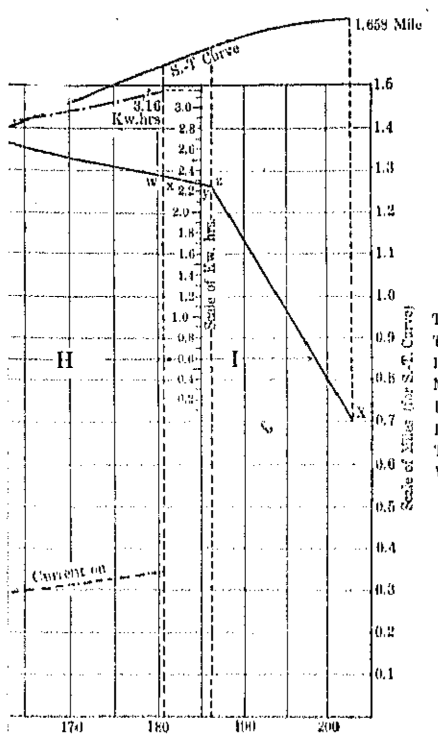
The method of finding distances used in the paper that is before us is highly ingenious, though it is not quite new. It was brought to my knowledge a long time ago. It has been used in Germany many years, and it may have originated there. One of the speakers this evening, who himself learned to use this method in Germany, will perhaps be able to throw some light on the origin of the method. I have never taken much interest in methods intended to replace the integraph, because of their inherent inferiority and their limitations as compared with the methods employing the integraph.

The objection to these methods is as much of a practical, as of a theoretical character. A diagram (Fig. 4) has been prepared to make this clear and to show the difference between the two kinds of methods.

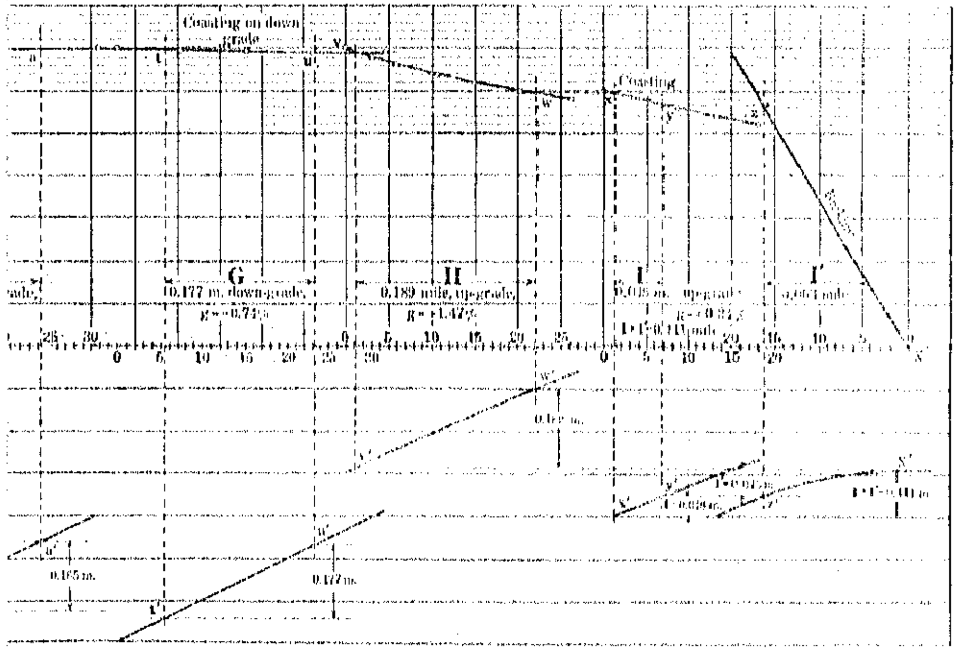
The upper portion of the diagram shows a *V-T* graph of the simplest form, comprising an acceleration period *O p q r s u v* over a distance of 0.112 mile, a coasting period (*x*, *w*) over a distance of 0.135 mile, and a braking period ($z\,t_4$) over a distance of 0.033 mile.

The middle part of the diagram shows the three integral-graphs corresponding to these three periods, and their use for cutting off the three portions of the *V-T* graph, and assembling them together into a complete *V-T* graph, in the manner already explained. The lower left-hand portion of the diagram illustrates the principle of the method used in Fig. 1 of the paper under discussion, and its application under very favorable conditions to the first portion of the *V-T* graph. The inclined lines, *O*-1, *O*-2, *O*-3, ... to *O*-16, are integral-graphs similar to the lines *O-s′* and *O-S* in Fig. 2. The line *O*-1 is the integral-graph or distance-time graph of a *V-T* graph of the constant velocity of 1 mi. per hr.; the line *O*-2 is the same thing for the *V-T* graph of 2 mi. per hr. constant velocity; and so on with the lines *O*-3, 4, 5 . . . . to 16. The integral-graph *O*-9 in Fig. 4, which corresponds to a constant velocity of 9 mi. per hr., is the same as the graph *OS′* in Fig. 2, though it is drawn to a scale that is twice as great. These distance-time graphs are all straight lines. Each one has a constant "slope" because the *V-T* graph from which it was obtained has the same ordinate value at every point. Being straight lines, the distance-time graphs *O*-1, *O*-2 . . . *O*-16 can be drawn readily by means of a straight edge; but even this simple operation can be performed more easily and accurately by the integraph; and the graphs shown in Fig. 4 were so drawn.

In order to utilize these straight line distance-time graphs, it is necessary to modify the actual *V-T* graph, or to suppose it to be modified, in a certain way. It is necessary to assume that the actual *V-T* graph can be replaced, for the purpose of obtaining its area, by another *V-T* graph in which the speed-changes take place at longer intervals and by sudden transitions from one "average" value to another. Thus, in Fig. 4, the actual *V-T* graph, *O p q r s u v* is supposed to be replaced by the broken line *O* 4 *A B C D E F G H I Jv*. In that case, the horizontal line 4-*A* represents the "average" velocity between 0 and 8 mi. per hr.;



Time of Run,	203 Seconds
Time of Run,	0.0564 Hour
Distance,	1.658 Mile
Mean velocity,	29.4 m.p.h.
Kw.-hours, per Train,	3.16
Kw.-hours, per Car Mile,	1.906
Train-weight, Tons,	35
Watt-hours, per Ton Mile,	54.4



[Mailloux]

and the other horizontal lines represent average velocities between other limits as follows: the line *B C*, the average between 8 and 10 mi. per hr.; the line *D E*, that between 10 and 12; the line *FG*, that between 12 and 13; the line *H I*, that between 13

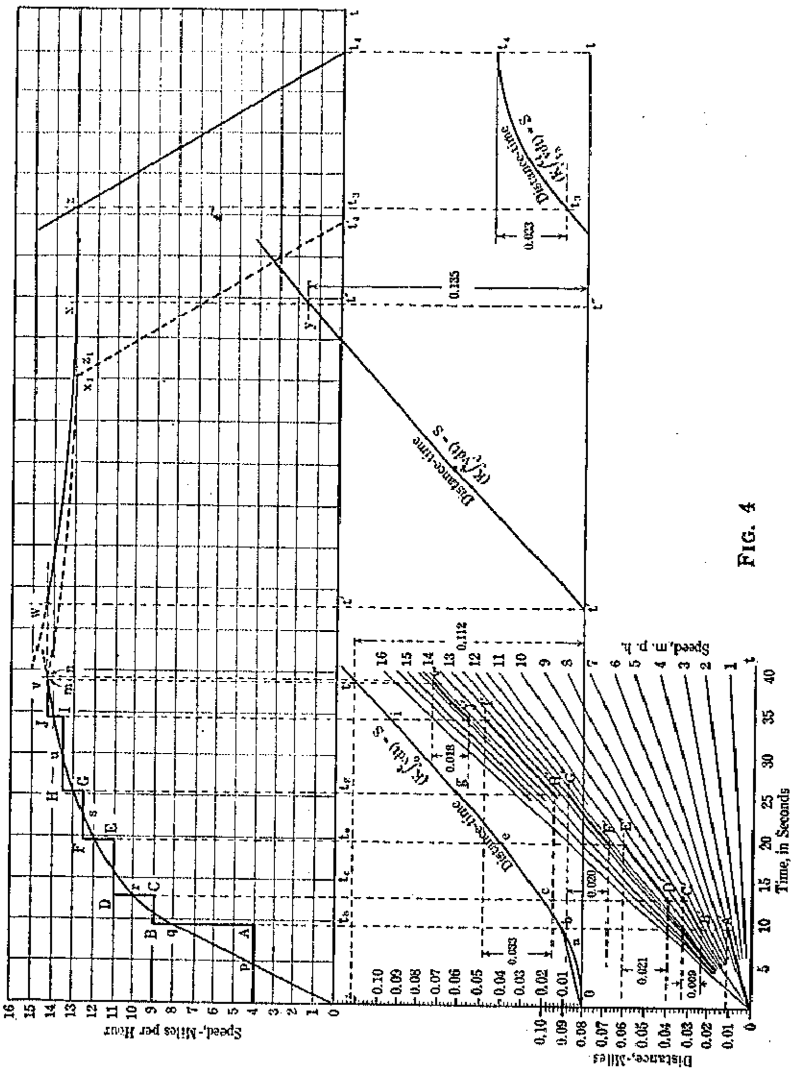


FIG. 4

and 14; the line *J v*, that between 14 and 14.25. The vertical line *B A* is extended downward until it intersects the integral-line *O* 4, corresponding to the average velocity 4*A* in the *V*-*T* graph. In like manner, the vertical line *D C* is extended downward to intersect the integral-line *O-q*, corresponding to the average velocity *B C*; and the integral-lines *O*-11, *O*-13.5, are intersected by the downward extensions of *F E*, *H G*, *J I*. As the ending point *m* of this portion of the run is not yet known (being, in fact, the very point which is to be found by the method under discussion) the vertical line *m v′* cannot yet be drawn. In the particular mode of using this method which is represented in Fig. 1 of the paper, these vertical lines are not actually drawn, but an exactly equivalent operation is performed by the aid of dividers, namely, the operation of cutting off the pieces of distance-time graphs which are shown by heavier lines (*O A′*, *B′ C′* *D′ E′*, *F′ G′*, and *H′ I′*) in Fig. 4. As it was desired to attain the very best precision possible, great care was used, in drawing these vertical lines, to "locate" them properly and to draw them all exactly parallel to the *V*-axis. It is obvious that a very slight shift of the lower end of any of these vertical lines to the right or to the left would alter the length of the portion of distance-time curve that is cut off by that vertical line; and it is also obvious that the same actual amount of shift will make a greater difference for the distance-time graphs corresponding to high average velocities than for those corresponding to lower velocities, because their "slope" is greater.

In using dividers instead of drawing lines to find, from the points *A C E G I*, the intersections *A′*, *B′*, *C′*, *D′*, etc., there is always a possibility of a slight error, due to the "shift" just mentioned in locating the ten points *A′*, *B′*, *C′* . . . . . *J′*, as it is very difficult to set dividers by the eye so that their points are exactly on a line parallel with another line, especially if the other line is at a little distance. There are still other chances of error. To obtain the exact distances corresponding to the five portions of straight-line distance-time graph (*O-A′*, *B′-C′*, *D′-E′*, *F′-G′*, and *H′-I′*), the geometrical projection of each of these portions on the *Y*-axis, *i.e.*, on the distance-scale, must be made. This work, which has been done in Fig. 4 by drawing, with very great care, horizontal lines through the points *A′*, *B′*, etc., has to be done by dividers in the case represented in Fig. 1 of the paper. Hence there are 20 operations to be performed with dividers, exclusive of those required for the final portion (*J′v′*), which is still undetermined. We must now obtain the sum of these projections, which will represent the distance from the beginning of the run to the point *I*; and we must subtract this sum from the known total distance for the first portion of the run, which is 0.112 mile. The sum may be obtained by dividers. In Fig. 4, each projection was very carefully measured by a finely graduated scale. The values found were:

Projection of *O −A′*............	0.011	mile
" " *B′−C′*............	0.009	"
" " *D′−E′*............	0.021	"
" " *F′−G′*............	0.020	"
" " *H′−I′*............	0.033	"
Sum........	0.094	"

Subtracting this sum from the total distance (0.112 mile) leaves 0.018 mile for the last part of the acceleration period of the V-T graph. Having decided upon an average velocity for this portion $J\,v$, a distance-time graph for that velocity (14.25 mi. per hr.) is drawn in the lower part of the diagram; and a portion thereof is cut off, $J'\,v'$, whose projection on the scale of distance is equal to 0.018 mile. By drawing a vertical line v'-v through the upper end v' of $J'v'$, we find the point of cut-off, m, for the V-T graph. The number of operations required with dividers has been increased by at least four, making a total of twenty-four for the acceleration period. It was possible to decrease the number of operations by reducing the number of "steps" of average velocity in the modified V-T graph; but this would have increased the error in another way, since the difference in area between the actual and the modified V-T graphs would then increase materially.

Let us now compare this method with the method employing the integraph. The operation is found to be exceedingly simple. We integrate the actual V-T graph $O\;p\;q\;r\;s\;u\;v$, as far as we like, by the integraph, obtaining the integral-graph $O\;a\;b\;c\;e\;g\;i\;t$. We then draw vertically from the base-line of the integral-graph a line equal by the scale of distance to 0.112 mile. A horizontal line through the upper end of this line intersects the integral-graph at the proper "ending" point t, and a line t-n drawn vertically from this point to the actual V-T graph cuts it off at the proper point n. The ending point, m, obtained by the other method is fairly near the correct point, n, because special efforts were made to secure the greatest possible accuracy by eliminating the use of dividers. When the different operations involved are performed with dividers, the difference between the points m and n may vary considerably.

The chances of error from the "modification" of the V-T graph would not be so great if the integration of the modified V-T graph were performed by the integraph, and the results obtained by one operation. This is shown in Fig. 4, where the integration of the modified V-T graph was actually "superposed" by the integraph upon that of the actual V-T graph. The straight line integral-graph $O\,A'$ forms a "chord" to the portion Oab. The other straight line integral-graphs ($B'C'$, etc.) also form "chords" to the actual integral-graph, which are visible in the lower portion, but practically coincide in the upper portion. The principal difficulty with the graphical method comes in assembling the partial integrations into a complete whole. This explains the statement already made that the difference between the two methods is as much of practical as of theoretical character. It amounts substantially to this: Whereas the integraph method enables the entire integral for any portion of V-T graph to be obtained, and the desired value to be determined by one single operation, the same integral, when obtained by the graphical method, can only be obtained in sections, which have to be joined together and summed up by methods which not only consume time but introduce chances of error.

The simplicity of the method employing the integraph is further shown in the coasting and braking portions of the run. A horizontal line $v\,w$ gives the "entering" speed for the coasting portion. The vertical line $w\,t'$ gives the starting point for the integral-graph $t'y$. This graph, cut off at an ordinate height equal to the proper distance (0.135 mile) gives the point of cut-off, y; and the vertical line $y\,x$ cuts off the *V-T* graph at the right point. A horizontal line, $x\,z$, gives the "entering" speed for the braking portion. The coasting and braking portions, when determined, are "shifted" to the left in the way already explained and as shown by dotted lines, so as to give the completed *V-T* graph.

In reply to the criticism made by Mr. Haar in this discussion, in regard to the accuracy of these methods, I may state in general that the accuracy is to a great extent within the control of the person making the predeterminations. I can speak from abundant experience, having seen the work done in many different ways, and I know that the percentage of accuracy depends greatly upon the person doing the work. It depends, to some extent, on the accuracy of the formulas that are used for train-resistance, upon the scales on which the drawings are made, and the precision of the methods of integration used. Where it is necessary to use average-velocity values and to determine the distance step-by-step, and especially when using dividers, one is liable to make cumulative errors, as already pointed out. These errors are eliminated if we are integrating for a whole section of line in one piece by means of an integrating device such as an integraph. So that, necessarily, a method involving the use of an instrument like the integraph is apt to be more accurate, especially if the scale is not too small and the drafting is done with some precision and accuracy, and also if the number of points determined is sufficiently great. In my lectures on the subject, I have shown the errors which result from making the "steps" or changes in velocity too large in plotting the *V-T* graph. It is possible to take rather large velocity-steps or changes at certain parts of the *V-T* graph and still have a fairly high degree of accuracy; but at other parts it is not wise to do so. In order to obtain a certain degree of accuracy, one must plot the curve with reasonable care and use a sufficient number of points. In any case, there should not be any difficulty in obtaining as close a degree of precision of predetermination by that method as by any other method used in the drafting room in electrical engineering.

N. W. Akimoff: Under the name of starting curve or archoid, the writer proposes a curve, to his knowledge quite original, the object of which is to embrace, in one equation, the peculiarities of *starting* a motor, a locomotive, an engine, etc.

The subject is so broad that only the simplest features of it will be considered in what follows.

Engineers are quite often confronted with such problems, or troubles, as, for instance, the necessity of fuses of abnormal amperage for starting a comparatively small motor; or, for example, the apparent weakness of the pins of a shaft coupling, of the ropes of an elevator, of a car coupler, of a shaft or its key, etc.

In all these instances the factor of safety, adopted in the design, may have been quite liberal, and the whole trouble arises from the fact that, in starting, this factor of safety may shrink down to almost nothing, while being altogether sufficient for steady running.

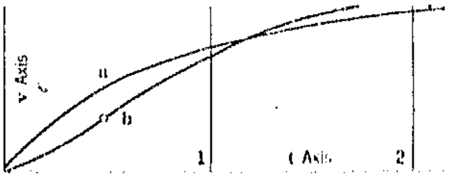


FIG. 7

In schools we are taught to design a shaft or a coupling for so many h.p. and so many rev. per min. without being in the least concerned as to *how it gets there.* And in dynamics we sometimes deal with problems, where the acceleration is changing *uniformly*, or, very seldom, is varying according to some prescribed law, purely arbitrary and from engineering viewpoint, meaning absolutely nothing.

Yet there are certain limitations in the phenomenon of starting, certain things which *may* take place and others which *cannot* take place at all.

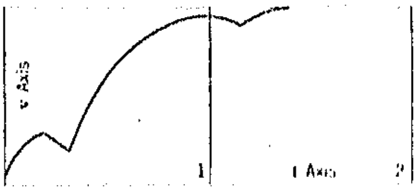


FIG. 8

The proposed curve, while not at all universal, may be of considerable use in practise, both in designing and in testing machinery.

If time, t, in seconds, be taken as abscissas, and the speed, v, (in ft. per sec. or in rev. per min.) be laid off as ordinates, then the proposed equation is

$$v = N\left(1 - \frac{1}{e^{bt^2+ct}}\right) \dots \qquad (1)$$

where N is the normal speed (linear or rotational) and b and c are constants; e being, of course, the Napierian base = 2.71828.

It is easy enough to see that, in the beginning of motion, when $t = 0$, v also reduces to zero; while after a considerable period of time, when t is very great, $b\,t^2 + c\,t$ tends to infinity, so that v reaches its normal, maximum, value, N; but t does not have to be infinite, in order that the speed may reach its full value. It will easily be seen that when the exponent, $b\,t^2 + c\,t$, equals only 4.5 or 5, the speed is already over 99 per cent of the normal; so that, for practical purposes, 5 or 5.5, at the most, is the maximum value required for the exponent $b\,t^2 + c\,t$. Thus, for instance, if $b = 1$ and $c = 4$, then the full speed is reached practically in one second.

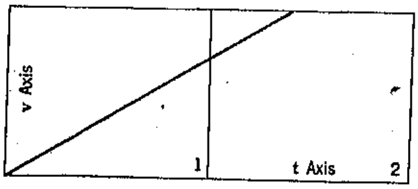


FIG. 9

This curve will be smooth in appearance (Fig. 7) as shown by a or b. In general it can be said, before any investigation has been made, that one's common sense will more readily accept this curve as likely to illustrate the true nature of starting, than for instance the fancy curve of Fig. 8, which is quite impossible, or for that matter, the curve of Fig. 9, which is rather improbable in practise; the latter curve, where the speed is merely proportional to the time, means that the acceleration is constant and corresponds simply to the case of falling bodies, having, as a rule, no place in the dynamics of starting. The curve shown in Fig. 10 is perfectly feasible, but it merely consists of several separate curves, each similar to that of Fig. 7.

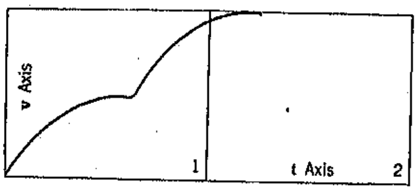


FIG. 10

To return to the archoid: the coefficients b and c are not necessarily positive, but cannot be both negative at the same time; one of them can be 0; if $b = 0$, we have what may be called the *simplified* curve, in contradistinction to the *complete* curve, in which either c alone is $= 0$, or both b and c differ from zero. A very great variety of curves may thus be derived, depending upon the values of the constants b and c.

The simplified curve

$$v = N\left(1 - \frac{1}{e^{ct}}\right) \,.\,. \qquad (2)$$

for $c = 0.5$, 1, 2 and 5, is given in Fig. 11. The complete curve is shown in Fig. 12; here b has been taken as $= 1$, while c has been given values 0.2, 0.5, 1 and 1.2.

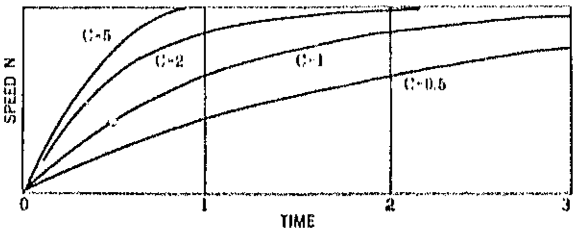


Fig. 11

The simplified curve may answer in a great variety of cases; its layout is particularly easy, especially if a table of multiples of the common logarithm of e, say from 1 to 100, has been computed once for all ($e = 2.71828$; its common log $= 0.43429$). The slide rule can be used for calculations. The simplified curve cannot have any points of inflection.

The complete curve may or may not have a point of inflection, regarding which a few remarks will now be made. We know from the elementary calculus that, in order to have a point of inflection, the second derivative must vanish. This, in our case, leads to the quadratic expression

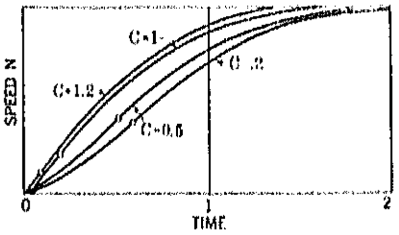


Fig. 12

$$4\,b^2t^2 + 4\,bct + (c^2 - 2b) \ldots\ldots \qquad (3)$$

If this $= 0$, the roots are $= \dfrac{-c \pm \sqrt{2b}}{2b}$. Hence, if the curve is to have a point of inflection, b cannot possibly be negative. If c is positive, there will be only one point of inflection, namely, if $\sqrt{2b}$ is greater than c. If c is negative, there might be one point of inflection, *i.e.*, if c is less than $\sqrt{2b}$; or, if c is greater, in absolute value, than $\sqrt{2b}$, there will be two points of inflection.

Thus $b = 2$, $c = -3$, will mean that there are two points of inflection, at 5/4 and $\frac{1}{4}$; while $b = 2$, $c = -1$, will mean only one point of inflection, *i.e.*, at $t = \frac{3}{4}$. If, however, the expression (3) is not $= 0$, there cannot be any points of inflection. The great importance of the points of inflection will become more apparent after their dynamical meaning is explained.

Prior to that we will say a few words regarding the acceleration as given by our curve. It will be readily understood that the first derivative of (1), or, which is the same thing, the tangent of the angle α, (Fig. 13), represents the acceleration of motion as characterized by the curve. The analytic value of the acceleration is, therefore,

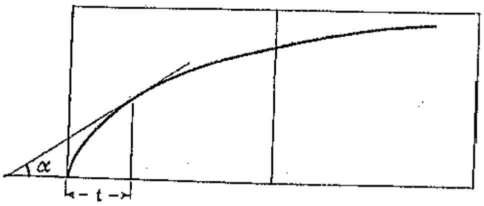


FIG. 13

$$a = N \frac{2\,bt + c}{e^{bt^2 + ct}} \cdots\cdots \qquad (4)$$

which, for the simplified curve ($b = 0$) becomes

$$a_s = N \frac{c}{e^{ct}} \cdots\cdot \qquad (5)$$

The Fig. 14 shows the acceleration curve for a simplified curve ($b = 0$, $c = 1$); while Fig. 15 gives the acceleration curve for a complete archoid ($b = 1$, $c = 0.5$).

One point of inflection means the maximum acceleration, while two points of inflection mean, in our case, that at least one of them will correspond to maximum acceleration.

We will easily realize that the archoid cannot be tangent to the axis of v at $t = 0$, since this would mean infinite acceleration, which no machine could stand. On the other hand, it will be readily understood that it is perfectly feasible to have maximum acceleration not at the beginning of the motion, but somewhere between the beginning and the time at which the full speed is reached.

It is of extreme importance for a practical man to know when this occurs and to have an idea, even if only approximate, as to the value of the acceleration. Only having these data in mind can the designer lay out a machine in which the factor of safety will not be lower, at any time, than the value originally intended. Any other "assumption" is mere guesswork. It will of course be remembered, that linear acceleration, if multiplied by the mass, gives the acting force; while, in rotary motion, the angular acceleration, when multiplied by the moment of inertia, gives the acting torque (or moment) at that time.

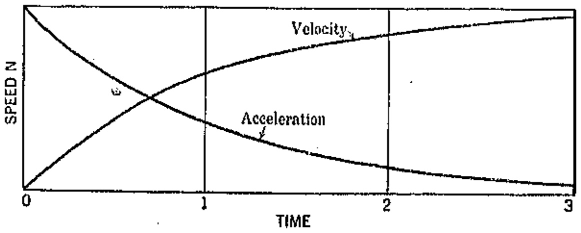


Fig. 14

In practise, the only difficulty will be the finding of the constants b and c. They cannot be very well figured out and will have to be determined from tests of machinery of similar types. In order to facilitate matters it will be of advantage to remember that the area of the archoid (Fig. 16), for any time t, represents the space (linear or angular, according as we have translation or rotation) traveled since the beginning of motion. In practise it will be found much easier to measure this than the actual velocity, corresponding to the given time t. This remark may help to find a few of the values of v, say v_1, v_2, v_3, corresponding to time t_1, t_2, t_3; remembering, also, that we have, at the end of the starting period, (when the full speed has been reached) v = say N and $t = T$, we thus have several (say four) sets of data, from which to determine b and c.

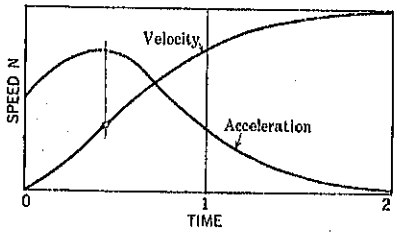


Fig. 15

Using the elementary rules of the theory of least squares we now proceed as follows: let us denote $b\,t^2 + c\,t$ simply by A, so that $v = N\left(1 - \frac{1}{e^A}\right)$....[see (**1**)], whence $A = \log_e \frac{N}{N - v}$ =, say, B.

Now, from our observations, we have the so-called observation equations, corresponding to various values of t and v, as for instance t_1, v_1; t_2, v_2; t_3, v_3; and, finally, T and N.

Thus we have $A_1 = B_1$; $A_2 = B_2$; etc. etc., or

$$\left.\begin{aligned} bt_1^2 + ct_1 &= B_1 \\ bt_2^2 + ct_2 &= B_2 \\ bt_3^2 + ct_3 &= B_3 \\ bT^2 + cT &= B_T \end{aligned}\right\} \ldots \qquad (6)$$

These are our observation equations. From these we form the so-called normal equations: in order to do so, we first multiply each equation of the group (**6**), throughout, by the coefficient of b in it, and add the results; then, second, we multiply each of the equations of the group (**6**) by the coefficient of c in it, and add the results.

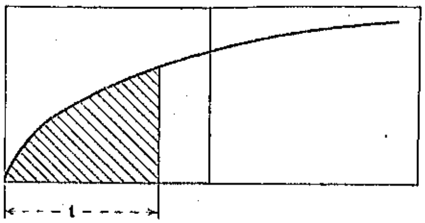


FIG. 16

Thus we have two normal equations

$$\begin{aligned} b\,(t_1^4 + t_2^4 + t_3^4 + T^4) + c\,(t_1^3 + t_2^3 + t_3^3 + T^3) \\ = B_1\,t_1^2 + B_2\,t_2^2 + B_3\,t_3^2 + B_T\;T^2 \;\therefore. \\ b\,(t_1^3 + t_2^3 + t_3^3 + T^3) + c\,(t_1^2 + t_2^2 + t_3^2 + T^2) \\ = B_1\,t_1 + B_2\,t_2 + B_3\,t_3 + B_T\;T \end{aligned} \qquad (7)$$

from which we can readily determine b and c. The equations (**7**) are so easy that no general formula will be given for their solution.

As soon as b and c are known, we need not really go to the trouble of plotting the archoid itself, unless we have any special reason for so doing; all we have to do is to introduce the constants b and c into the expression (**3**) as well as into the equations (**4**) or (**5**). This will give us what we want to know most of all, the value of the acceleration, and the points of inflection, if any.

If this article is somewhat long, it is due to the writer's earnest desire to make it easy for the practical engineer. A mathematician would understand everything right from the first glance at the proposed formula (1).

The writer sincerely hopes that the archoid may be introduced into practical life, where it might clear up more than one mystery.

NOTE. *The Integral Curve.* The object of the archoid is to obviate, as much as possible, the necessity of graphical methods: the time-speed curve is plotted from actual observations, then the constants are derived from it and, finally, the acceleration is found by substituting the latter into the corresponding formula.

But, in some cases, especially where motion *in general* is considered (and not only the starting or accelerating period), it is necessary to use graphical methods, and in this connection a few words may be mentioned here regarding the integral curve, which is so useful in such investigations. In fact this curve can be used in many branches of engineering, but we shall limit ourselves to its application to the time-speed problems.

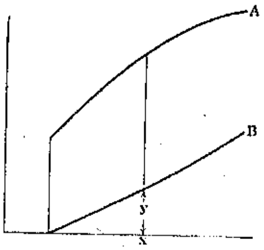


FIG. 17

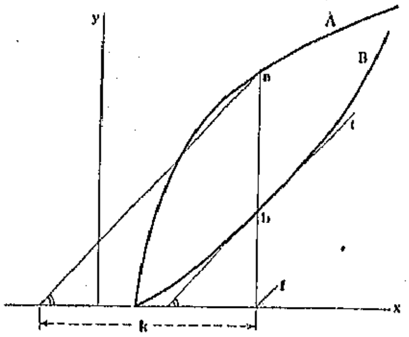


FIG. 18

A curve *B* (Fig. 17), of which any ordinate *y* represents to some certain scale the area of another curve *A*, corresponding to the same abscissa *x*, is called the integral curve of the proposed curve *A*. Conversely, *A* is called the differential curve of *B*. Being given either curve we can readily construct the other curve, as will be presently explained.

It will be easily seen that, in our original problem, the archoid, or in general the time-speed curve is really the integral curve of the time-acceleration curve; on the other hand this same time-speed curve is the differential curve of the time-distance curve (we mean *distance* in general, that is, in angular sense for rotation and in lineal sense for translatory motion). So that, dynamically (not electrically), the characteristics of the motion are known just as soon as we have the time-speed curve, since both the acceleration and the space can be immediately derived from it.

The following general remarks regarding the integral curve can here be made:

1. The integral curve of any given or proposed curve can readily be constructed with a great degree of precision by means of an ordinary planimeter.

2. The inverse process of finding the differential curve of a given or proposed curve is less accurate (Fig. 18): here, for any point *b* of the proposed curve *B* we find the corresponding point *a* of the required differential curve *A* as follows: from *f* we lay off a suitable constant *k* to the left and then through *l* we draw a parallel to the tangent *t* to the proposed curve at *b*. The constant *k* is really arbitrary and is chosen so as to secure the curve *A* to the desired scale.

3. If the proposed curve is parallel to the axis of *x*, the integral curve will be a straight line through *O* (Fig. 19).

4. If the proposed curve is a straight line through *O* (Fig. 20), the integral curve will be a parabola, tangent to the axis of *x* at *O*.

The integral curve possesses many other most interesting properties, which will not be gone into in this communication. It is possible to design special planimeters, called *integraphs*, to draw it mechanically. It appears that Dr. Mailloux, who is a well-known expert on such matters, has even succeeded in constructing a device for the inverse problem, that is, for drawing the original curve from a given integral curve.

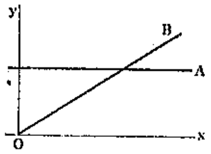


FIG. 19

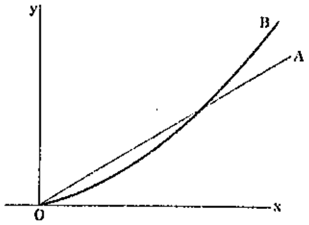


FIG. 20

F. Castiglioni: I am much interested in the subject of speed-time curves. I am one of the few persons in this country who have made a specialty of this line of work. I do not refer to the kind of speed-time diagram work represented by the diagram for a so-called "average run"—which is a rather elementary piece of work—but I mean high-grade work of the kind referred to by Dr. Mailloux, speed-diagrams which take into account every change of grade, every "slowing down" in train-speed due to track-curves, crossings and bridges and other service-conditions.

I learned the methods which I use for doing this work in Germany some years ago. I did not know, at the time, their origin. It is only recently that I learned of the pioneer work of Dr. Mailloux, and of his celebrated paper published in the A. I. E. E. Proceedings in 1902.

The matter of greatest importance in any method of plotting speed-time curves is, as Dr. Mailloux has pointed out, to determine when to stop, in going along with the speed-time curve for a given grade, so as to conform at the right time and place to the new conditions for the change of grade for the next portion of the run.

Use has been made for many years of auxiliary curves of distance-time, based upon average velocities, for determining distances, as is done in Fig. 1 of Professor Woodruff's paper.

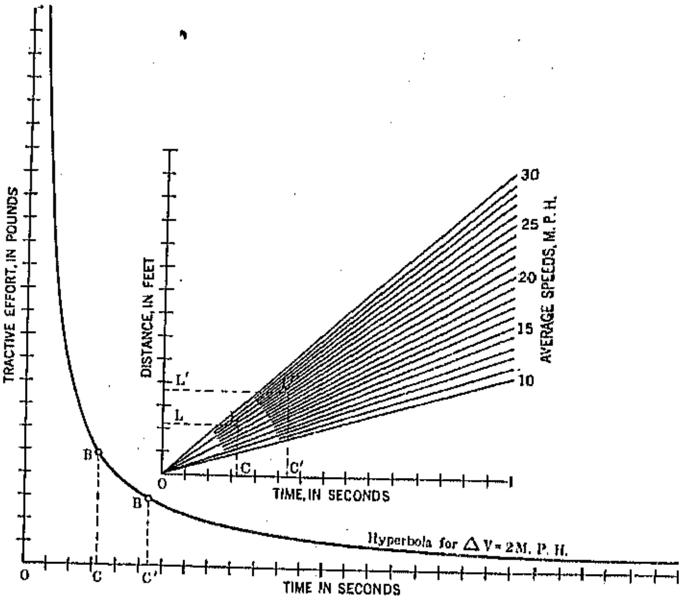


Fig. 21

The arrangement of these curves which I have used (Fig. 21) is a little different, and I think has advantages in some respects.

The method which I use, in preference to all others, for cutting off portions of speed-time curves at the proper points, involves the construction of the *speed-distance* curve. The speed-distance curve is a curve very much like a speed-time curve, and it is of interest and utility aside from its use in giving the proper distance-points for the speed-time curve. The speed-time curve is of interest to the motor manufacturer as a means of determining the power and energy consumed, but to the operating man, the speed-distance curve is really of greater interest than the speed-time curve. By the method which I use both of these curves are plotted on the same sheet.

The conditions under which we have to work in making predeterminations by means of speed-diagrams are usually more or less the same. We have the detailed profile of an existing or proposed road; we have information about the speed-requirements and regulations prescribed, the weight of the train, the number of driving motors, the required schedule-speed, and the specification of the number and length of stops. Previous experience with similar cases, or else an approximate predetermination by reference to an " average run ", will tell us the motor capacity and gear-ratio, which should be chosen tentatively.

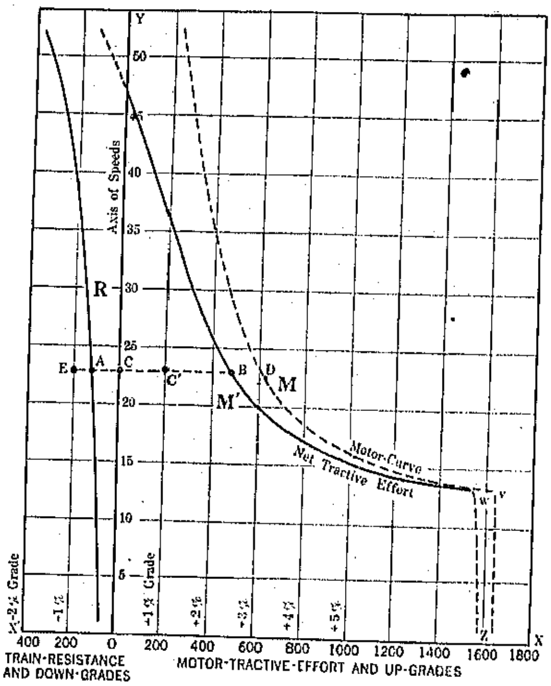


FIG. 22

We are to ascertain, by the aid of speed-diagrams, if the proposed schedule speed can be attained, and what will be the temperature and the power-consumption conditions with the motors and gear-ratio under consideration.

I will describe briefly the method of plotting speed-curves which I use. It is a German method, which I have simplified somewhat and adapted to American units.

For using this method certain curves similar to those used in the Mailloux method must be plotted on a " chart ". The characteristic curve of the motor that is to be used is plotted by reference to speed and tractive effort as co-ordinates. This gives the motor-curve *M* in Fig. 22. By reference to a suitable formula for train-resistance, a curve, R, is plotted to represent the tractive effort requisite to overcome the train-resistance for the weight of train *per motor*, (which is assumed to be 10 tons, in Fig. 22). The curve R is plotted to the left of the axis of speeds, $O\ Y$, but with the same scale of values as for the curve M. From the curves M and R a curve of *net tractive efforts*, M', is obtained by plotting the curve M anew from the curve R as a *base*, instead of the speed-axis $O\ Y$. At any given speed, the motor tractive effort, $C\ D$, measured from the curve M, will be the same as the tractive effort $A\ B$, measured from the curve M'; and as the portion $A\ C = B\ D$ represents the tractive effort expended in overcoming train-resistance, the remainder, $C\ B$, will represent the *net* tractive effort available for producing acceleration.

The retarding forces due to up-grades and the accelerating forces due to down-grades, are also taken into account by an adaptation of the Mailloux method. Lines corresponding to different grades (1 per cent, 2 per cent, 3 per cent, etc.) are drawn on both sides of the speed-axis, $O\ Y$, the lines for up-grades being on one side, and those for down-grades on the other, as in the Mailloux "Chart of Coefficients." The difference between the two charts in this respect is that the grade-lines on the Mailloux chart are based upon forces *per ton*, whereas in this case they refer to forces for the *tons of train-weight per motor*. The chart shown in Fig. 22 is used to obtain the net accelerating and retarding forces in substantially the same manner as the chart of coefficients of the Mailloux method, but the values obtained are expressed in different units. The net accelerating force, which is equal to the distance, $C\ B$, between the curve M' and the axis $O\ Y$, for a level track, becomes decreased to $C'B$ for an up-grade of 1 per cent, and increased to $B\ C + E\ C = B\ E$ on a down-grade of 1 per cent. The net accelerating and retarding forces for other grades are obtained in like manner.

For plotting the speed-curves, a strip of cross-section paper is used, of width suitable for the scales desired for speed, current, power, etc., and of length suitable for the total distance of the run or series of runs to be plotted. On this strip of paper, time and distance are both measured by horizontal distances. The distance-scale is continuous, but the time-scale starts anew at each station. The fact that the distance-scale is continuous enables all the stations, grades, curves, and the speed-regulations for crossings, bridges, etc., to be indicated at the proper points, on the sheet, before beginning to plot the speed-curves.

We first plot the portion of speed-time curve for the beginning of the run. This is an inclined straight line below the critical speed, v, Fig. 22, at which the accelerating force ceases to be constant (as represented by the dotted line $w\ z$) begins to decrease with increasing speed in the manner shown by the motor-curve M. After the straight-line portion of the speed-time curve is plotted, the corresponding portion of the speed-distance curve is drawn. This is not a straight line, but a curved, parabolic line, the necessary points for which are obtained by a simple calculation, from the area of the initial portion of the speed-time curve (which is that of a right-angled triangle). It can be shown that the distance covered in a given time during the initial portion of the run is equal to the speed squared divided by a constant, which is proportional to the acceleration, and depends also upon the units employed for speed and distance. The co-ordinates of these parabolic curves vary with the grade. The necessary points for plotting them for a few grades are obtained by calculation; and the curves for all the grades can then be plotted on a separate sheet, from which the points required for plotting portions of these curves may then be taken, as wanted. The braking curve at the end of the run may then be drawn. It is also an inclined straight line, and, consequently, the corresponding speed-distance curve will also be of parabolic form, and the necessary points for plotting it can be determined in the same manner as for the initial portion of the run. To plot the speed-time curve between the initial and braking portions, a step-by-step process is employed, as in the Mailloux method and its modifications. Having determined upon the speed-increment which is to be used in plotting the curves (say, for instance, supposing we are taking $\Delta V = 2$ mi. per hr.), we can use the well-known hyperbola, as first employed in the Mailloux method, for finding the time-increment corresponding to the average net tractive effort obtained for that speed-increment, from the curves in Fig. 22. Fig. 21 shows the hyperbola in question. The average tractive effort, for any speed-increment, is taken off from Fig. 22, and is transferred by dividers to Fig. 21. Supposing it to be equal to BC in Fig. 22, then, in Fig. 21 the vertical distance $B\ C$ will correspond to the time interval $O\ C$. If the net tractive effort is $B\ C'$ in Fig. 22, then, in Fig. 21 the corresponding time-interval will be $O\ C'$. The time-increment thus obtained is transferred to the plotting sheet by dividers. The distance-increment is determined from the time-increment by a method which is practically the same as that mentioned in Professor Woodruff's paper, namely, by the use of a set of integral lines, each of which corresponds to an "average" velocity. These integral lines are shown in Fig. 21, for average speeds ranging from 10 to 30 mi. per hr.

The time-scale for this portion of Fig. 21 is the same as that for the hyperbola and for the plotting sheet. The distance-scale is the same as that used on the plotting sheet. The time-increment, such as $O\ C$ or $O\ C'$, is obtained by means of the hyperbola, is taken off by dividers and transferred to the plotting sheet. It is also transferred to the time-scale of the distance-diagram in Fig. 21. One point of the dividers is set on the distance-axis and the dividers are moved upward with the points in a line parallel with the time-axis until the right-hand point comes to the integral line for the proper average speed (which is 23 mi.

per hr. for the case shown in Fig. 21). When this line is reached the vertical distance from the time-axis, $L\,C = O\,L$, or $L'C' = O\,L'$, according to the case, is the required distance-increment, which is then transferred by dividers to the plotting sheet, and laid off horizontally from the last point plotted. The speed-distance curve is then plotted to this point by making the speed at that distance-point exactly the same as the speed at the corresponding time-point of the speed-time curve. The next, and all succeeding points are determined and plotted for both curves in the same manner. Thus, both the speed-time and distance-time curves are plotted simultaneously, step-by-step, the speeds going upwards for acceleration and downwards for retardations, the proper net values of tractive effort being taken, in every case, from Fig. 22, for the grade, etc., for the corresponding portion of the run; and it is the speed-distance curve which shows at what point on the line the train is, and which indicates where a given portion ends and a new portion begins. When the "run" is completed, the accuracy of plotting may be checked up by planimetry of the area of the speed-time curve. With ordinary care in the plotting, the difference between the actual and the theoretically correct curve ought to be within 3 per cent, which is satisfactory, considering the fact that the motor-curves are likely to be from 3 per cent to 5 per cent off the correct values.

The use of the speed-distance curve to supplement the speed-time curve, and to assist in its construction, is the characteristic feature of this method, distances being represented in all other methods by a distance-time curve, in which the scale of distance is vertical instead of horizontal, and therefore much more limited than in this method. The speed-distance curve, aside from its greatly facilitating and expediting the operation of cutting off and connecting the different portions of runs at the right *time* and *distance*, has the advantage of furnishing a curve similar to the speed-time curve, which gives information of interest to the operating department of the road because it shows the actual speed at every portion of the *distance*, whereas the speed-time curve only shows the speed at every instant of *time*.

I have used this method with success for extended and comprehensive studies of electric traction possibilities, in important cases like the Pennsylvania electrification at Philadelphia, the elevated and subway systems in New York, etc., where there were many different kinds of trains and schedules to be considered, for all which predeterminations had to be made. An idea of the rapidity of this method may be obtained from the sample curves which I have with me.* Two of these curves refer to 16 miles of road with 25 stations, 145 changes of grade, 50 curves, and a few speed-regulations. The actual work of plotting of these curves in pencil was done in 25 hours and 15 minutes. To do the same work by calculation methods instead of this graphical method, would have taken at least five times more time.

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*Curves exhibited at meeting but not embodied here.

F. E. Wynne: The method shown in the paper is appar a slight modification of a method described by Philip Da in his book, *Electric Traction on Railways*, in that the de hyperbola and nest of straight-line curves have been sup posed upon a motor curve plotted in the usual form. this and other graphic methods undoubtedly save conside time where a large number of car performance curves mu plotted for varying service conditions, yet I am unable to with the author that his method saves time " even when on to plot but a single speed-time curve for a particular n load ". Considerable observation leads me to believe tha step-by-step method of calculation and plotting speed- curves, together with the use of a planimeter, which elimi the necessity for the speed-distance curve or time-distance c is more rapid than any graphical method where not more three speed-time curves have to be made for a given weight motor.

Experience in instructing students and others has convi me that students in particular should become thoroughly fam with the step-by-step process before being permitted to [illegible] graphical processes, because by intelligently following the step step method, they secure a much clearer understanding of actual mechanics of car performance. After they have such understanding, graphical methods are of great assistance i ducing to a minimum the labor involved in calculating a l series of performance curves.

N. W. Storer: The description of the method which Mailloux offers tonight is of the greatest interest to us all, we shall be very much interested in seeing it amplified and wri out, accompanied by the curves. It looks like a very sin and accurate method.

Mr. Castiglioni's method I can vouch for as quite reliable accurate, as well as quick. He did considerable work in sight some few months ago, and I can say that it was very and quickly done. There are any number of these graph methods, all of which are of advantage, especially to the men have worked them out. Any man who gets used to working one particular scheme is going to be at a disadvantage, when attempts to work on some different method, but I think we recognize that each of them has certain advantages.

E. E. Kimball: In the short time which remains I wish hurry through a description of two typical railway motor ch acteristic curves and show how valuable the slide rule is a handy substitute for the characteristic curves of an actual r way motor. The steps leading up to the selection of a moto do a given service without overheating, usually require exte similar calculations or follow the calculations of speed-time distance-time curves, but there are some short cuts which lead to a close approximation of the size of motors requir Furthermore, the ordinary characteristic curves giving spe tractive effort and efficiency of a railway motor, do not cont sufficient information regarding the resistance and core loss of the motor for one to determine the losses which have to be radiated in service or to correct a characteristic curve for a change in voltage conditions. From an analysis of these characteristic curves the writer expects to point out a procedure which he has found to be very useful in supplying this information when required.

The so-called polyphase slide rule—Fig. 23—is the same as the ordinary slide rule except that it has two additional scales; one in red between the *B* and *C* scales, which is the *C* scale inverted (reversed), and the other on the edge of the rule, which is the scale of the cubes of numbers on the *D* scale. If the ends of the scales are made to coincide as shown in Fig. 23, and values read from the *C I* and cube scales are plotted against corresponding values from the *A* scale as abscissas, the curves which result resemble the characteristic curves of a d-c. railway motor is shown by the dotted lines of Fig. 24. That is, from the "*A*"

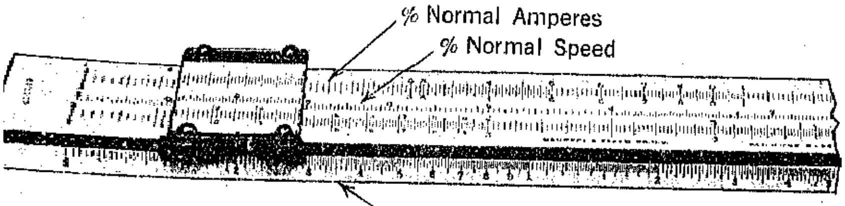

FIG. 23

ale is read per cent amperes, from the middle scale per cent eed, and from the scale on the edge of the rule per cent trac- ve effort. The setting of the slider in Fig. 23 gives the read- gs of speed and tractive effort corresponding to 160 per cent rmal amperes; that is, 79 per cent speed and 203 per cent trac- ve effort. In Fig. 24 are shown in solid lines the charac- ristic curves of a composite or typical railway motor in which e values are given in percentages of the one-hour rating of the otor. If the dotted lines are accepted as representing the ation between the amperes, tractive effort, and speed for ugh calculations, then it can be shown that the efficiency must constant throughout the entire range. The equations of the tted speed and tractive effort curves are as follows:

$$\text{Per cent speed} = \left(\frac{1}{\%\ \text{amp.}}\right)^{\frac{1}{2}}$$

d

$$\text{Per cent } T.E. = (\text{per cent amp.})^{3/2}$$

The writer has made no attempt to derive an equation which will represent the characteristics of a railway motor closer than the ones just given, for the reason that the chief value of these equations lies in the fact that it is easy to remember to read per cent amperes on the A scale, per cent speed on the middle scale and per cent tractive effort on the cube scale.

For speed-time and distance-time curves one is not so much interested in the relation between speed and amperes or tractive effort and amperes as he is in the relation between speed and tractive effort.

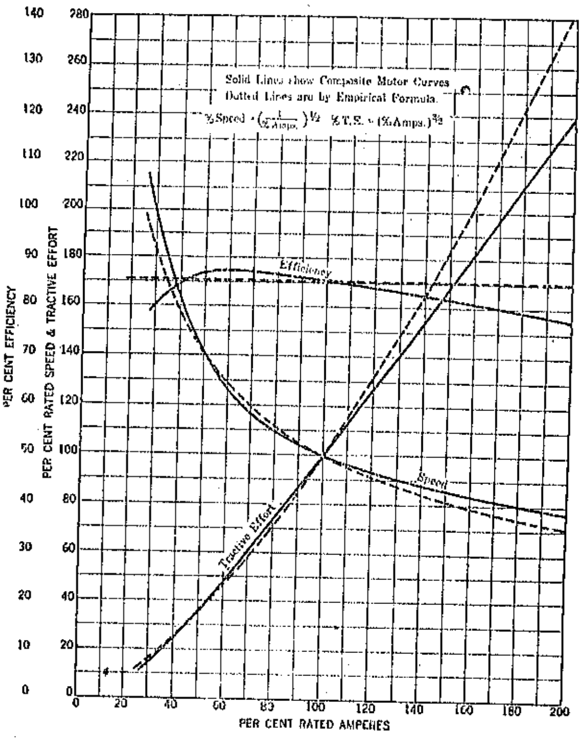

FIG. 24

From the above equations it follows that per cent speed $= \left(\frac{1}{\% T.E.}\right)^{1/3}$ or in other words: *The speed of a d-c. railway motor is approximately inversely proportional to the cube root of the tractive effort.*

The dotted speed curve in Fig. 25 is plotted with tractive effort instead of amperes as the variable, that is, the two tractive effort curves of Fig. 24 have been made to coincide and the speed curve modified so as to maintain the same relation between speed and tractive effort as exists in Fig. 24. The closeness with which the dotted and solid speed curves of Fig. 25 agree shows the relation between speed and tractive effort for the typical railway motor is closely represented by the rule just stated.

The value of this relation in determining the capacity of railway motors for a given service is best illustrated by an example.

Assume a 50-ton car to be geared for a maximum speed of 60 mi. per hr., a train resistance value of 25 lb. per ton at 60 mi. per hr. and a rate of acceleration of 0.8 mi. per hr. per sec.; to determine the h.p. capacity of motors required.

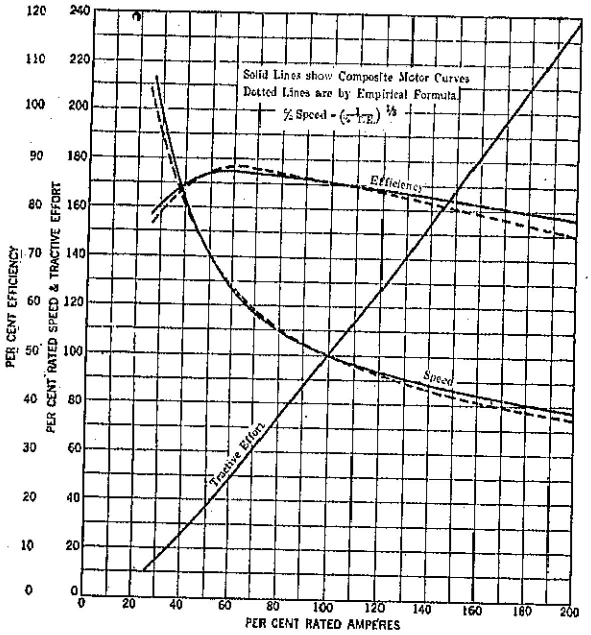

FIG. 25

At 60 mi. per hr. the tractive effort delivered by the motors just balances the train resistance, *i. e.*, 25 lb. per ton. The final speed reached on the control during the period of notching up (beginning of motor curve acceleration) is unknown, but we know what the tractive effort must be to give 0.8 mi. per hr. per sec. acceleration during the control period. It is 80 + 15 = 95 lb. per ton if we assume it takes 100 lb. per ton to produce 1 mi. per hr. per sec. and if the train resistance at this lower speed is taken at 15 lb. per ton.

By the rule just stated $\frac{V}{60} = \left(\frac{25}{95}\right)^{1/3}$

$$\text{or } V = 60 \times \left(\frac{25}{95}\right)^{1/3} = 60\ (0.263)^{1/3} = 38.5 \text{ mi. per hr.}$$

Likewise for any other speed the tractive effort can be obtained: that is, at 40 mi. per hr.

$$\frac{T}{25} = \left(\frac{60}{40}\right)^3$$

or

$$T = 25 \times \left(\frac{3}{2}\right)^3 = 84 \text{ lb. per ton.}$$

Thus, given one condition which must be satisfied, other points follow directly. That is, given the maximum speed and friction corresponding, the speed and tractive effort for any other point can be closely estimated. The usual procedure is as just outlined in the example above.

The equipment selected must be able to accelerate the car at the rate of 0.8 mi. per hr. per sec. up to 38.5 mi. per hr. without overheating in service. A car geared for a maximum speed of 60 mi. per hr. would not usually be used in a frequent stop service, hence high and frequent accelerations are not likely to occur, and it may be assumed that if this rate of acceleration does not exceed the one-hour rating of the motors the equipment will have capacity to do the service, that is:

$$\text{h.p. required} = \frac{50 \times 95 \times 38.5}{375} = 488$$

let us say four 125-h.p. motors.

One would look for characteristic curves of 125 h.p. motors and select a gearing which would give sufficient tractive effort at 60 mi. per hr. to balance the friction.

For lighter and slower speed cars which are generally used in frequent stop service a rate of acceleration of 0.8 mi. per hr. per sec. is not sufficient either for performing the usual schedules nor does it leave enough margin for radiating the losses in service. It is usual to select an equipment for these services which will produce an acceleration of 1.00 to 1.50 mi. per hr. per sec. at the one-hour rating of the motors. This is on the basis of non-ventilated motors.

Ventilated motors radiate losses much faster than the non-ventilated pole type, hence the h.p. rating of motors, if ventilated motors are proposed, will be less than found by the above method. As a first approximation, 80 per cent of the values found above will lead to some definite design of motors for which the radiating constants are known. From these it can be determined what the probable heating will be in service.

To segregate the losses of a railway motor and thereby determine its resistance, the writer has found that the core loss may be represented by the equation $CL = K\, I^{1/3}$, where K is a constant and I represents current.

The Standardization Rules of the A. I. E. E. (Appendix I of Rules) suggest that the gear and friction losses be taken at five per cent for all loads above $\frac{3}{4}$ load for approximate determinations when tests are not available.

Then from an efficiency curve plotted in this fashion we may select two points above $\frac{3}{4}$ load and write the equation for the total losses, eliminate the terms containing core loss and solve for R.

Thus for 3/4 and 3/2 load
if I = Amperes at 3/4 load
$2\,I$ = Amperes at 3/2 load
L = Core loss at 3/4 load
$\sqrt[3]{2}\,(L)$ = Core loss at 3/2 load
K_1 and K_2 = Total losses in per cent at 3/4 and 3/2 load respectively.
= 100 − per cent efficiency at 3/4 and 3/2 load respectively.
E = Rated voltage of motor or voltage marked on curve.

$$\text{Then } I^2R + L + \frac{5}{100}\,EI = \frac{K_1EI}{100} \text{ at } 3/4 \text{ load} \qquad (1)$$

$$\text{And } (2I)^2R + \sqrt[3]{2}\,L + \frac{5}{100}\,E\,(2\,I) = \frac{K_2\,E\,(2I)}{100} \text{ at } 3/2 \text{ load} \qquad (2)$$

Or eliminating L and substituting 1.26 for $\sqrt[3]{2}$

$$2.74\; I^2R + \frac{3.7\,E\,I}{100} = \frac{(2K_2 - 1.26\,K_1)}{100}\,EI$$

$$R = \frac{(2K_2 - 1.26\,K_1 - 3.7)\,E}{2.74 \times 100 \times I}$$

$$\text{Simplified, } R = \frac{(8\,K_2 - 5\,K_1 - 15)\,E}{1100\quad I} \text{ approximately}$$

From the derivation of this formula it follows that care must be taken to select two points both of which are above 3/4 load, and the loads must bear the relation 2 to 1. That is, if one point is taken at 7/8 load the other must be taken at 7/4 load, etc. I is the current corresponding to the lesser of the two points chosen.

Example. Find the per cent copper and core loss represented by the typical characteristics shown in Fig. 24 or 25.

These curves are shown over a sufficient range to obtain three determinations of the resistance. For check readings, we will take the losses in pairs as follows:

K_{80}, K_{160}; K_{90}, K_{180}; K_{100}, K_{200}

$K_{80} = 100 - 86.5 = 13.5$; $K_{90} = 14$; $K_{100} = 14.5$;

$K_{160} = 100 - 82.0 = 18.0$; $K_{180} = 20.5$; $K_{200} = 22.0$

$$R = \frac{(8 \times 18 - 5 \times 13.5 - 15)\,E}{1100 \times 80} = 0.0007\,E$$

$$R = \frac{(8 \times 20.5 - 5 \times 14 - 15)\,E}{1100 \times 90} = 0.0008\,E$$

$$R = \frac{(8 \times 22.0 - 5 \times 14.5 - 15)\,E}{1100 \times 100} = 0.000805\,E$$

Ave. $R = 0.00077\,E$

$$\text{Per cent } I^2R \text{ (1-hr rating)} = \frac{I^2R \times 100}{E \times I} = 100 \times 0.00077 \times 100$$

$$= 7.7 \text{ per cent}$$

Per cent CL (1-hr. rating) $= 14.5 - (5 + 7.7) = 1.8$ per cent.

The accuracy of this determination of the resistance of a motor depends upon how accurately the efficiency can be read. A single determination may be 25 per cent out because of accumulated errors in reading the efficiencies, but usually the error is less than 10 per cent.

E. C. Woodruff: With regard to the accuracy of a graphic method—when the data are given in the form of a curve and the object of the calculation is to obtain another curve, graphic methods used for the intermediate steps will not reduce the accuracy of the calculation. Any analytical steps used will involve a double translation from curves to tabulated data and vice versa, and will give even more chances for errors in said translations.

C. O. Mailloux (communicated after adjournment): A comparison of the chart used in the method of Mr. Castiglioni (Fig. 22) with that shown in Fig. 9 of my 1902 paper, indicates clearly the identity of the principle of the two methods. Curves M, M' and R in Mr. Castiglioni's chart are the same as curves M, N and R' (and also R) in my paper. They seem, at first, to be different because the axes of co-ordinates are disposed differently and the scale of tractive efforts is also different. In my chart, speeds are plotted as abscissas and tractive efforts as ordinates, because this puts the independent variable, speed, in the proper cartesian position and relation with respect to the "function," *i.e.*, the tractive effort. In Mr. Castiglioni's chart these relations are transposed, which makes, apparently, the speed a function of the tractive effort, something not physically possible. The arrangement is not logical, and I fail to see that it has any advantages whatever to excuse it. In regard to tractive effort scales, there are two differences. First, I deal, in Fig. 9, with all accelerating and retarding forces on the basis of their action on *one ton* of train-weight, whereas, in Mr. Castiglioni's chart, these forces are dealt with on the basis of the action produced *per motor*. The advantage of this change appears very doubtful. Second, in Fig. 9 of my paper, the curve R represents the actual train-resistance per ton, same as the formula by reference to which the curve was plotted. The lines parallel with the speed-axis which correspond to up-grades and down-grades also represent forces per ton. The great advantage of this plan is that the curves R and Q and the grade-lines in my chart are definite and require no change with the train-load per motor. In Mr. Castiglioni's Fig. 22, the curve R and the grade-lines have to be changed every time the train-weight per motor changes. In my chart, a change in motor-load requires only the curves M and N to be changed. In reality, the curve N does not have to be changed, because by drawing the curve R both above and below the axis of speeds, as is done in Fig. 9, the net values of tractive effort are obtained by the difference in ordinates between curves M and R. As pointed out in my discussion, several curves of tractive effort M corresponding to different motors and loads, can be put on the same chart. In regard to the measurement of tractive effort, I still prefer to translate tractive effort directly into acceleration-values, and to use a scale of *accelerations* as is done in Fig. 9, because the acceleration-values indicated by such a scale convey a definite idea of what is actually happening and tell us something we want to know, namely, how rapidly the train is *gaining* or *losing* speed, at any moment. Tractive effort and acceleration bear to each other the relation of *cause* and *effect*. The first represents the *agency*, the second the *result* produced by it. In this case we have to measure and express a *result*, not a *cause*, and it is wrong to express the result in terms of the cause. A scale of acceleration-coefficients such as used in Fig. 9 of my paper expresses the *result* produced, *directly* and in the *correct unit*, the mile per hour per second, (or the kilometer per hour per second), which unit is now recognized and adopted internationally since the Turin Electrical Congress in 1911. The thought of even trying to express acceleration in terms of pounds of tractive effort per second per second is supremely ridiculous. The use of a scale of tractive effort in place of a scale of accelerations has no practical advantages and it is open to the objection of being both illogical and inconsistent. A scale of tractive efforts may be used, if desired, to *supplement* the scale of accelerations, but it should never be used to *replace* it. In Fig. 9 of my paper, the scale of acceleration may be converted into a scale of tractive efforts per ton by multiplying the acceleration values by the constant 91.2. In some cases, a scale of tractive efforts has been added to the chart; but the use of this scale for the purposes for which the acceleration scale is manifestly the proper scale has not been encouraged; and when once students become familiar with the theoretical principles involved, they see the logic and propriety of the units and scales used and prefer them to all others; and the scale of tractive efforts loses all interest and utility.

The instances of rapid work done by Mr. Castiglioni by his method are very interesting as evidence of the merits of graphical methods. I confess that I am still a bit skeptical on the point of accuracy, because the possibilities of error noted in connection with Prof. Woodruff's method do not appear to be wholly eliminated. The use which is made of the speed-distance curve is ingenious, but the method by which the distance increments are obtained, being based upon straight-line integrations corresponding to average velocities, as in Prof. Woodruff's method, appears to be open to the same objections and the same liability to cumulative errors. As pointed out and as shown by the comparison given in Fig. 4 of my discussion, this method of obtaining distance and time increments is at best much more laborious and far less accurate than the method based upon the use of the distance-time integral, as obtained by the integraph. When the speed-distance curve is desired, as a supplement to the speed-time curve, it can be readily and quickly plotted from the distance-time curve obtained by the integraph.

The chart method described in my 1902 paper is capable of doing work at least as rapidly; and, of course, from the point of view of accuracy, not only in plotting the speed-time curve, but also and more especially the "subsidiary" curves, which, as shown in my paper, are the ones of greatest interest and importance, the chart method described in my 1902 paper, when used with the integraph, can fearlessly challenge and meet all methods that have come to light thus far.

D. D. Ewing (communicated after adjournment): In the first paragraph of his paper, Prof. Woodruff makes the statement, "Students that have struggled with the usual step-by-step process* * * * seem to acquire a new interest in the subject when this method is proposed." I wonder if this "new interest", is not, partly at least, the more or less fictitious sort of interest which students display whenever a short-cut method of any kind is proposed. In other words, it may be that they are more interested in finding a method of lessening their labor than they are in the theory of the thing they are studying.

Viewing the method from the standpoint of a teacher of engineering there are the following objections to it: 1. It does not give the student the drill on the underlying theory of the curves that the step-by-step method does. The writer does not wish to be understood as decrying the use by students of graphical methods of solving problems. Such methods are extremely valuable whenever they enable the student to get a clearer conception of the problem. However, this type of graphical method belongs to what might be termed the "slide rule" class, and just as any person of ordinary intelligence can be taught to solve more or less difficult problems, rapidly, with the slide rule, without understanding the theory underlying the problem, so can a person be taught to use this type of graphical method. Such methods tend to become mechanical, thereby facilitating the solution of problems. We are not so particular about the student's "speed" as we are about his understanding. The step-by-step method which brings in the elementary theory underlying the construction of the curve in the calculations for each point gives the student a much firmer grasp on the theory than could any graphical method. 2. The large number of curves on the sheet tends to confuse the student. This objection is so obvious that it does not need discussion.

Viewed from the standpoint of the practising engineer, the method presents some valuable features. It is compact even if it is somewhat complicated. Where a large number of similar speed-time curves is to be calculated, the method would probably effect a considerable saving in time besides eliminating to a large degree the mental strain that always accompanies analytical methods of solving problems.

In the last sentence the statement is made that " the method saves time and trouble when one has to plot but a single speed-time curve for a particular motor load." The truth of this statement is not obvious. While the writer has not given this particular method a thorough tryout, his past experience leads him to believe that unless a large number of speed-time curves is to be calculated, the step-by-step method is the shortest, provided care is taken to systematize the work. All time saved by the graphical method must be saved while calculating that part of the acceleration line of the curve which covers the time during which the motors are accelerating with line voltage across their terminals. Where the runs are short, but few points on this part of the curve are needed and therefore there is little opportunity to shorten the time required for the calculation of the entire curve.

Presented at the 302d Meeting of the American Institute of Electrical Engineers, New York, December 11, 1914.

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EFFECT OF ALTITUDE ON THE SPARK-OVER VOLTAGES OF BUSHINGS, LEADS AND INSULATORS

BY F. W. PEEK, JR.

ABSTRACT OF PAPER

The dielectric strength of air decreases with decreasing pressure and increasing temperature; that is, with the density. Therefore, at high altitudes where the barometric pressure is low, brush discharge starts and spark-over takes place at lower voltages than at sea level. The effect of air density on corona, and spark-over between spheres, etc., has already been given.

In the following investigation the effect of altitude and temperature on the surface spark-over of leads and insulators was studied by placing them in a large wooden cask and gradually exhausting the air. Correction factors are given for various standard types. The spark-over voltage decreases almost directly with the air density.

The following gives an idea of the magnitude of the correction: The spark-over voltage of a certain string of insulators at 25 deg. cent. is

Kv.	Altitude	Possible Location
300	0	Sea level
250	5,000 ft.	Denver
205	10,000 ft.	Colorado

THE following investigation was made to determine the effect of air density, and therefore of altitude or barometric pressure, and temperature, upon the spark-over voltages of leads, insulators, etc.

The dielectric strength of air decreases with decreasing pressure and increasing temperature; that is, with the relative density or with the average spacing of the molecules. If the relative density is taken as unity at a standard pressure of 76 cm. and a temperature of 25 deg. cent., the relative density at any other pressure and temperature is

$$\delta = \frac{3.92\, b}{273 + t}$$

where b = barometric pressure in cm.

and t = temperature in degrees cent.

For the uniform field between parallel planes the spark-over voltage decreases directly with δ. If e is the spark-over voltage for a given spacing at $\delta = 1$, the spark-over voltage e_1 at $\delta = 0.5$ is

$$e_1 = 0.5\, e$$

The effect is the same for the same value of δ whether δ is changed by temperature or by pressure. This has been shown elsewhere.* For non-uniform fields, as those around wires, spheres, insulators, etc., the spark-over voltage decreases at a lesser rate than the air density. The theoretical reasons for this have been given, as well as the laws for regular symmetrical electrodes, for cylinders, and spheres.†

It is, however, not possible to give an exact law covering all types of leads, insulators, etc., as every part of the surface has its effect. The following curves and tables give the actual test results on leads, insulators, and bushings of the standard types. The correction factor for any other lead or insulator of the same type may be estimated with sufficient accuracy. When there is doubt, δ may be taken as the maximum correction. It will generally be advisable to take δ because the local corona point on leads and insulators will vary directly with δ. This is so because the corona must always start on an insulator in a field which is locally more or less uniform.

The tests were made by placing the leads or insulators in a large wooden cask 2.1 meters high by 1.8 meters inside diameter, exhausting the air to approximately $\delta = 0.5$, gradually admitting air and taking the spark-over voltage at various densities as the air pressure increased. The temperature was always read, and varied between 16 and 25 deg. cent. The cask is shown in Fig. 1.

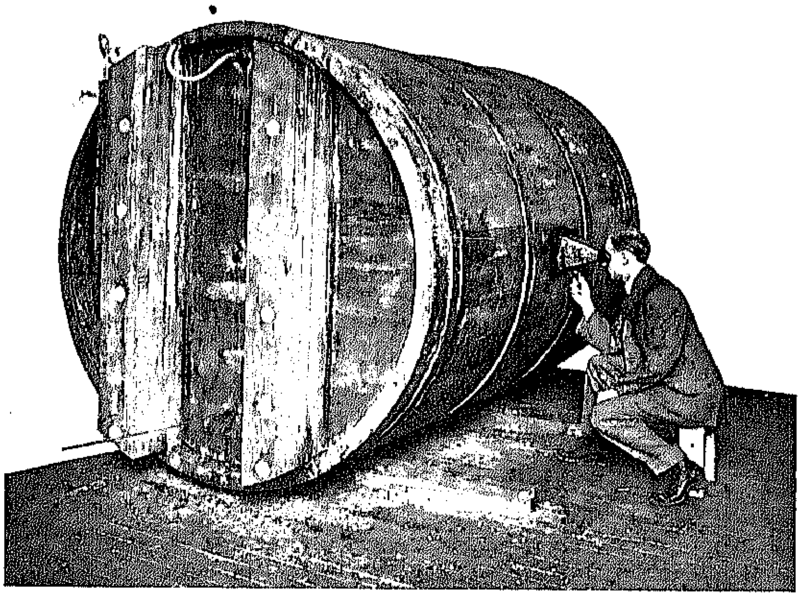
At the start a number of tests were made to see if a spark-over in the cask had any effect upon the following spark-overs by ionization or otherwise. It was found that a number of spark-overs could be made in the cask with no appreciable effect. During the test, the air was always dried and the surfaces of the insulators were kept clean.‡

Table I is a typical data sheet. Tables II to VI give even values of δ and the corresponding measured correction factors. If the spark-over voltage is known at sea level or $\delta = 1$ (76 cm. bar., temperature 25 deg. cent.), the spark-over at any other value of δ may be found by multiplying by the corresponding correction factor. It will be noted that in most cases the correction factors are very nearly equal to δ.

**Law of Corona II*, A. I. E. E. TRANS., 1912, p. 1051.

†*Law of Corona II*, A. I. E. E. TRANS., 1912, p. 1051, and
Law of Corona III, A. I. E. E. TRANS., 1913, p. 1767.

‡In these tests, corrections have been made for wave shape, etc., and the voltages checked by *sphere gap*. Voltages measured by needle gap are incorrect and indicate higher voltages than really exist.



[PEEK]

FIG. 1—CASK FOR STUDY OF VARIATION OF SPARK-OVER AND CORONA VOLTAGE WITH AIR DENSITY OR ALTITUDE

TABLE I

SUSPENSION INSULATOR

Bar. cm.	Vac. cm.	Pressure cm.	Temp. cent.	δ	Kilovolts arc-over
75.4	37.4	38.0	22.	0.50	121.0
"	34.3	41.1	"	0.54	131.0
"	30.0	45.4	"	0.60	144.0
"	26.4	49.0	"	0.65	158.5
"	23.0	52.4	"	0.70	165.0
"	19.3	56.	"	0.74	177.5
"	17.5	57.9	"	0.77	183.2
"	15.0	60.4	"	0.80	195.0

TABLE II

LEADS. (See Fig. 17)

δ	Correction Factor for Lead Shown in			
	Fig. 2	Fig. 3	Fig. 4	Fig. 5
1.00	1.00	1.00	1.00	1.00
0.90	0.92	0.91	0.92	0.92
0.80	0.83	0.82	0.83	0.85
0.70	0.74	0.72	0.75	0.77
0.60	0.70	0.65	0.64	0.66
0.50	0.61	0.56	0.54	0.57

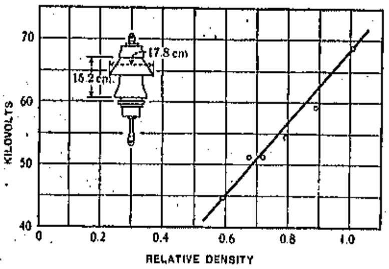


FIG. 2—ARC-OVER VOLTAGES AT VARIOUS DENSITIES

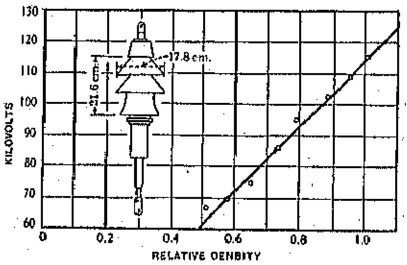


FIG. 3—ARC-OVER VOLTAGES AT VARIOUS AIR DENSITIES

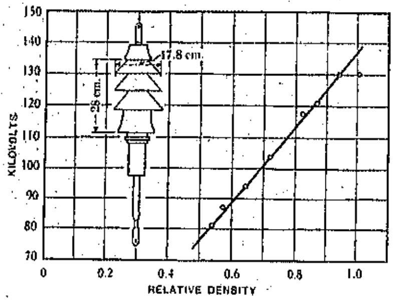


FIG. 4—ARC-OVER VOLTAGES AT VARIOUS DENSITIES

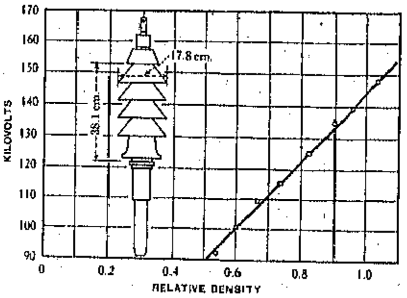


FIG. 5—ARC-OVER VOLTAGES AT VARIOUS DENSITIES

TABLE III

Post and Pin Insulators. (See Fig. 20)

δ	Correction Factor for Insulator Shown in		
	Fig. 6	Fig. 7	Fig. 8
	Post	Pin	
1.00	1.00	1.00	1.00
1.90	0.93	0.91	0.94
0.80	0.84	0.81	0.86
0.70	0.76	0.73	0.75
0.60	0.68	0.62	0.65
0.50	0.60	0.52	0.53

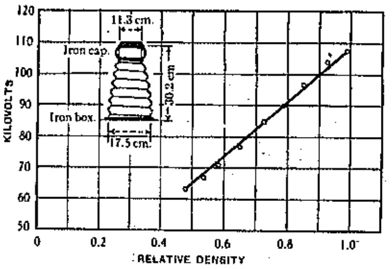


Fig. 6—Arc-Over Voltages at Various Air Densities.

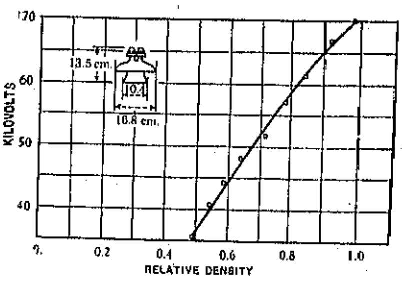


Fig. 7—Arc-Over Voltages at Various Densities

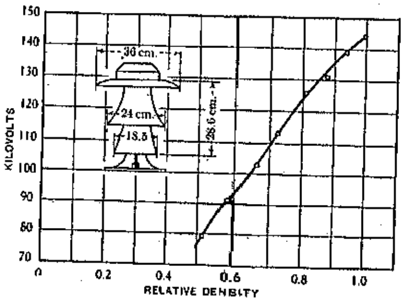


Fig. 8—Arc-Over Voltages at Various Densities

TABLE IV

SUSPENSION INSULATOR FIG. 9. (See Figs. 18 and 10)

δ	Correction Factor for Units in String as follows				
	Number of Units				
	1	2	3	4	5
1.00	1.00	1.00	1.00	....	....
0.90	0.96	0.93	0.90	....	....
0.80	0.91	0.84	0.80	....	....
0.70	0.86	0.76	0.70	....	....
0.60	0.80	0.66	0.60	....	....
0.50	0.72	0.55	0.50	....	....

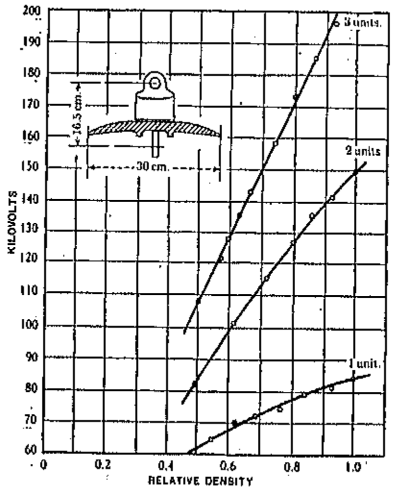


FIG. 9—ARC-OVER VOLTAGES AT VARIOUS AIR DENSITIES

TABLE V

SUSPENSION INSULATOR, FIG. 10. (See Figs. 18 and 19)

δ	Correction Factor for Units in String as follows				
	Number of Units				
	1	2	3	4	5
1.00	1.00	1.00	1.00	1.00	1.00
0.90	0.95	0.91	0.90	0.90	0.91
0.80	0.89	0.81	0.81	0.81	0.82
0.70	0.80	0.72	0.72	0.72	0.73
0.60	0.70	0.63	0.63	0.63	0.65
0.50	0.57	0.53	0.53	0.53	0.57

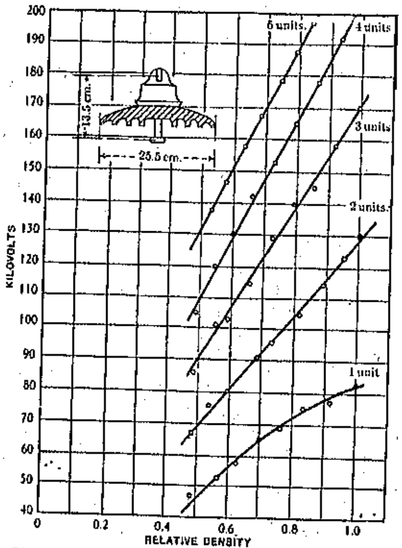


FIG. 10—ARC-OVER VOLTAGES AT VARIOUS AIR DENSITIES

TABLE VI
SUSPENSION INSULATOR, FIG. 11. (See Figs. 18 and 19)

δ	Correction Factor for Units in String as follows Number of Units				
	1	2	3	4	5
1.00	1.00	1.00	1.00	1.00	....
0.90	0.94	0.92	0.90	0.90	....
0.80	0.87	0.84	0.80	0.80	....
0.70	0.81	0.73	0.70	0.70	....
0.60	0.72	0.63	0.60	0.60	....
0.50	0.62	0.52	0.50	0.50	....

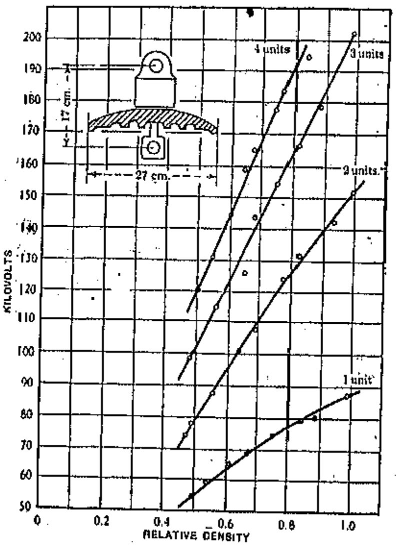


FIG. 11—ARC-OVER VOLTAGES AT VARIOUS AIR DENSITIES

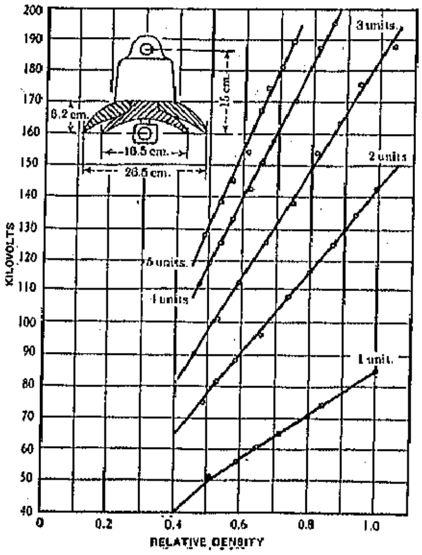


FIG. 12—ARC-OVER VOLTAGES AT VARIOUS AIR DENSITIES

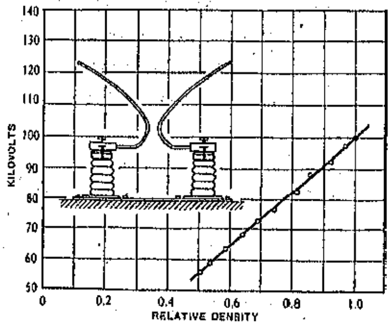


FIG. 13—ARC-OVER VOLTAGES AT VARIOUS AIR DENSITIES
Horn gap spark-over. Gap spacing 14 cm, Diameter of horns 1.27 cm,

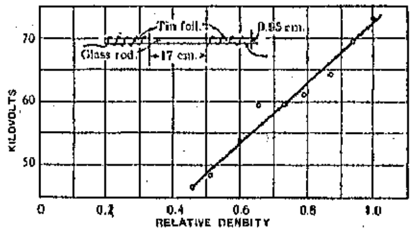


FIG. 14—ARC-OVER VOLTAGES AT VARIOUS AIR DENSITIES

Fig. 15 is a curve giving different altitudes and corresponding δ at 25 deg. cent. If the spark-over voltage is known at sea level at 25 deg. cent., the spark-over voltage at any other altitude may be estimated by multiplying by the corresponding δ, or more closely, if the design is the same as any in the tables, by the correction factor corresponding to δ. If the local corona starting point is known at sea level, it may be found for any altitude by multiplying by the corresponding δ. The barometric pressure corresponding to different altitudes is given in Fig. 16. Figs. 17 to 20 show the insulators used in these tests.

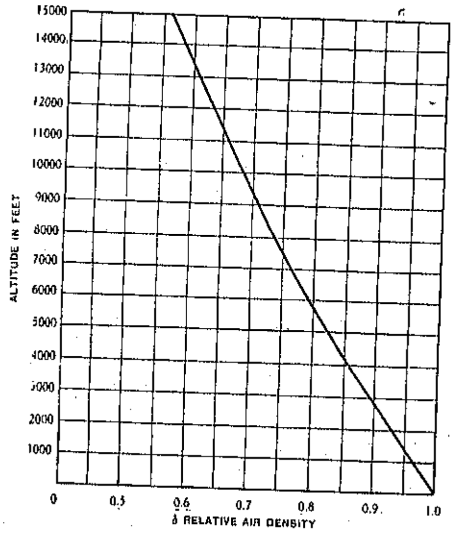


FIG. 15

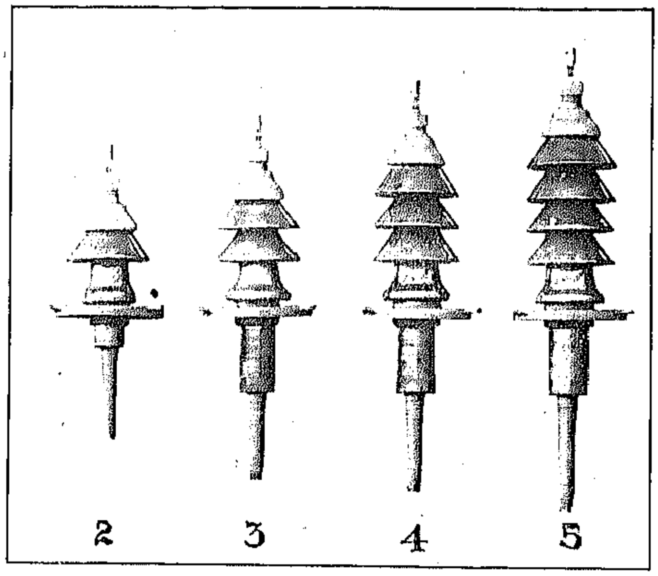
As an example of the methods of making corrections: assume a suspension insulator string of four units with a spark-over voltage of 205 kv. (at sea level, 25 deg. cent. temperature). $\delta = 1$. What is the spark-over voltage at 9000 ft. elevation and 25 deg. cent.?

From Fig. 15, the δ corresponding to 9000 ft. is

$$\delta = 0.71$$

Then the approximate spark-over voltage at 9000 ft., 25 deg. cent., is

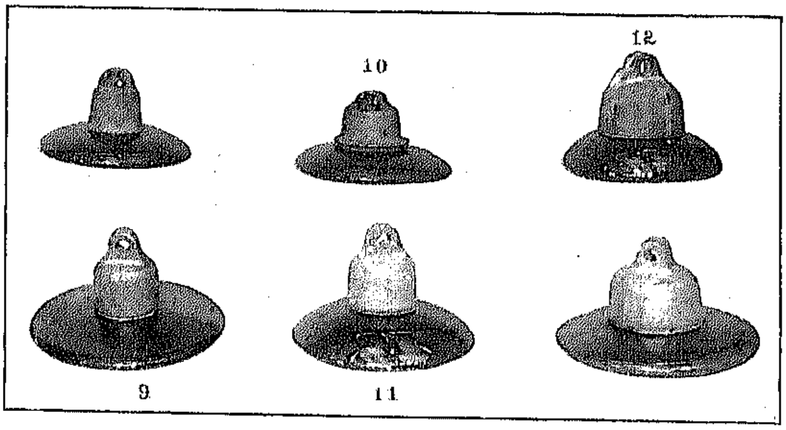
$$e_1 = 0.71 \times 205 = 145 \text{ kv.}$$



[PEEK]

FIG. 17—SPARK-OVER TAKEN ON UPPER PART OF LEAD—LOWER PART IN OIL

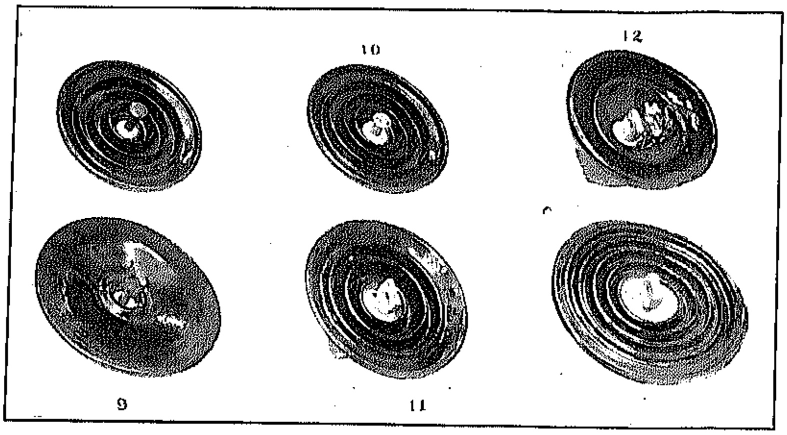
Numerals refer to figure number of data curve.



[PEEK]

FIG. 18—TYPES OF PORCELAIN INSULATORS TESTED AT VARIOUS AIR DENSITIES

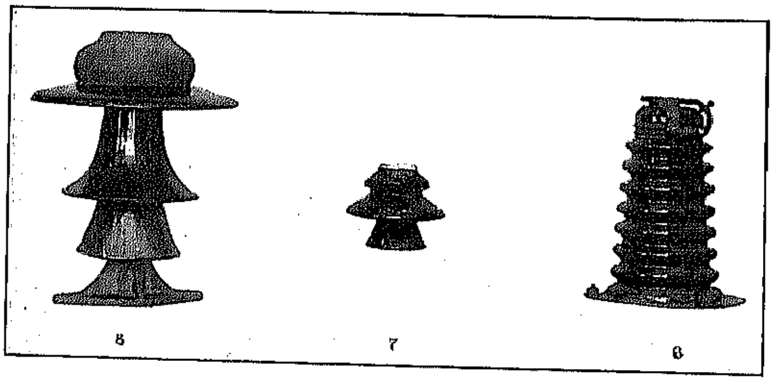
Numerals refer to figure number of data curve.



[PEEK]

FIG. 19—TYPES OF PORCELAIN INSULATORS TESTED AT VARIOUS AIR DENSITIES

Numerals refer to figure number of data curve.



[PEEK]

FIG. 20—TYPES OF PORCELAIN INSULATORS TESTED AT VARIOUS AIR DENSITIES

Numerals refer to figure number of data curve.

If this happens to be the insulator of Fig. 10, the correction factor corresponding to $\delta = 0.71$ is found in Table V, by interpolation, to be 0.73. The actual spark-over voltage for this special case is

$$e_1 = 0.73 \times 205 = 150 \text{ kv.}$$

The first estimate is on the safe side and close enough for all practical purposes. Thus, for practical work the correction may generally be made directly by use of Fig. 15.

The spark-over voltage of an insulator is 100 kv. at 70 cm. barometer and 20 deg. cent. What is the approximate spark-over voltage at 50 cm. barometer and 10 deg. cent.?

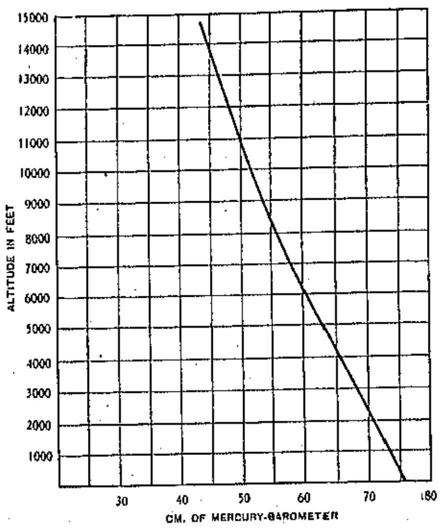


FIG. 16

$$\delta_1 = \frac{3.92 \times 70}{273 + 20} = 0.94$$

$$\delta_2 = \frac{3.92 \times 50}{273 + 10} = 0.61$$

$$e_1 = 100 \times \frac{0.61}{0.94} = 65 \text{ kv,}$$

If the local corona starting point is known at, say, sea level, it may be found very closely for any other altitude by multiplying by the correction δ.

The spark-over voltage of insulators will vary somewhat from day to day, due to humidity. There is also some variation for different units. The humidity voltage variation on the insulator is possibly as high as 7 per cent, from day to day. Comparative tests of different types, when desired, should be made at the same time. The humidity correction, on the insulator itself, is too complicated to make and of no practical value. Care must be taken, however, to use a measuring gap unaffected by humidity; that is, a sphere gap.

Presented at the 302d Meeting of the American Institute of Electrical Engineers, New York, December 11, 1914.

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INSULATOR DEPRECIATION AND EFFECT ON OPERATION

BY A. O. AUSTIN

ABSTRACT OF PAPER

Investigation shows that insulator trouble increasing with time is not due to fatigue in the material under applied working loads, but rather to depreciation caused by the absorption of water by porous material or by the cracking of the dielectric from high internal mechanical stress set up by uneven temperature in the dielectric, or by greater expansion of cement or metal, or stress from a combination of these.

The shape of the dielectric may cause high maximum stresses under comparatively mild conditions, necessitating the working of material with a lower factor of safety than that permissible even in steel work. The high maximum internal stress under which insulators operate will cause considerable depreciation in some types through cracking, necessitating a careful study of the effect of depreciation upon the operation of the system. Trouble comes largely through the matching up of faulty parts so that the remainder of the insulator will be destroyed by a comparatively mild surge. Applying the theory of probability, it is then possible to obtain a relative operating hazard for the insulator under the same conditions or for varying degrees of depreciation.

An equation for the operating hazard may be developed which gives a good idea of the relative economic importance of the number of sections in the insulator, the magnitude of the switching surge and the rate of depreciation as affecting the reliability of the system.

The study of depreciation shows that routine tests which will tend to eliminate future depreciation, or refinements in the mechanical features of the insulator, are of far more importance in producing reliability than the designing of insulators to withstand extremely severe dielectric design tests, for insulators which may have extremely high dielectric strength will cause trouble through cracking from internal stress.

THE growing investments dependent upon the transmission line make the study of factors governing reliability in the insulator of ever-increasing economic importance. In view of this, it is hoped that this article will throw some light on insulator failures and be of assistance in deciding on the refinements and size of insulator necessary for a given system.

Even with more severe conditions placed on the insulator, recent lines have continued to make a much better showing. Some systems have had no insulator failures, while others have operated for a period of several years only to run into increasing trouble, in some instances necessitating the entire reinsulating of the line.

Where insulator trouble increases with time, it is only natural to attribute the trouble to fatigue in the insulator. Upon looking into the subject, however, it is evident that this is not necessarily the case, for the failures may be due to a number of entirely different causes.

Suspension insulators give the best available data, although failures of pin type insulators have been far more numerous, in some instances a visual inspection showing cracks developed in over 60 per cent of the insulators.

A few pin type insulators which have cracked after several years' service are shown in Fig. 1. An examination of this class of failure shows that there must be a strong radial force which splits the outer parts or shears the head of the cylinder from the side wall. This force can come from several sources, but as the porcelain does not seem to be appreciably affected either mechanically or electrically outside of the cracks it would appear that the breakdown is due more to a rather high stress, than to a low stress acting for a long time.

It is quite likely that the stress set up is that due to uneven expansion from varying temperature and from an expansion of the cement.

Porcelain, like most dielectrics, is a very poor conductor of heat, so if the insulator has become hot in the sun or from surface leakage, and is then suddenly cooled by rain, there will be a considerable difference in temperature between the outer and inner parts. This difference in temperature may set up an average tensile stress of several hundred pounds in the outer members.

This average stress is hardly high enough to cause any damage, but the shape of the dielectric may be such that a very high maximum stress is set up, causing a crack, as along AB in Fig. 2.

There is no doubt that the defect comes from internal stress, but as this stress may be set up by uneven temperature and expansion in the dielectric or by cement expansion, it is not easy to determine the cause.

Tests on the insulators show that there may be considerable difference in temperature between inner and outer surfaces which may account for destructive stresses in some instances, but hardly accounts for failures in other cases, particularly where insulators have been known to crack in storerooms and in protected places where there has been no sudden change of temperature.

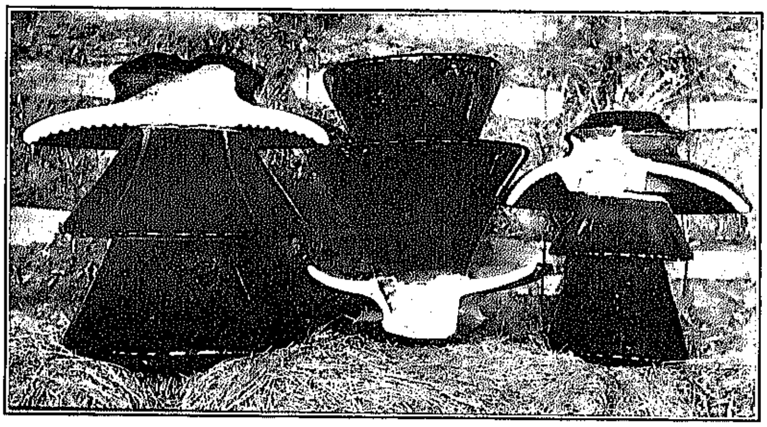

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FIG. 1

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FIG. 4

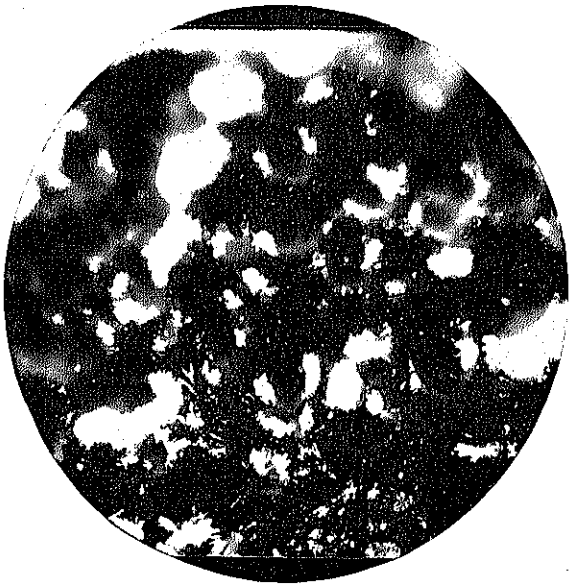

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FIG. 5

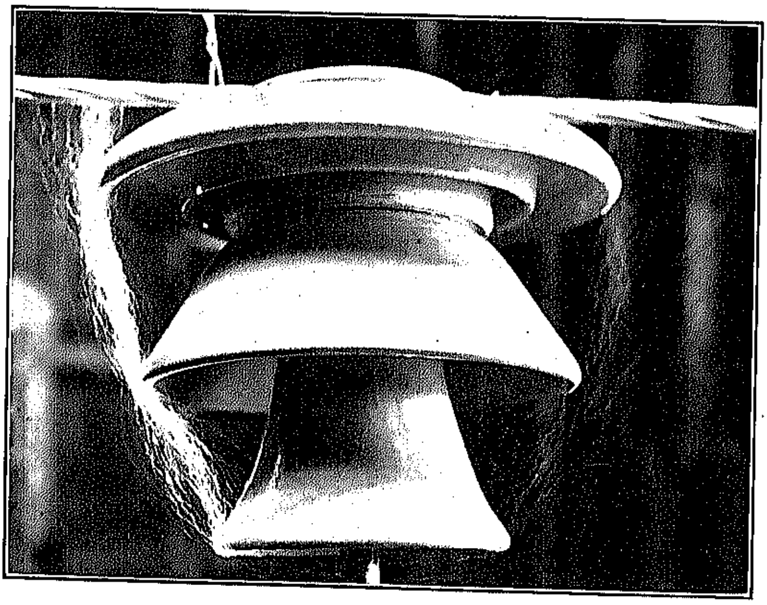

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FIG. 6

It is also significant that trouble usually develops at railway crossings first. While it is possible that the insulators may become hotter, owing to the black surface or increased leakage, it appears that the sulphur fumes in the smoke attack the cement and increase the crystalline growth, presumably of calcium sulphate. This crystallization causes expansion, setting up a stress which, combined with that due to difference in temperature, may produce exceedingly high strains.

It is not surprising that there should be some trouble from cement expansion, for in general, little attention has been given to this rather difficult subject, and even where there has been, it is difficult to predict expansion from the formation of acids by static discharge in the cement or effect of continued weathering.

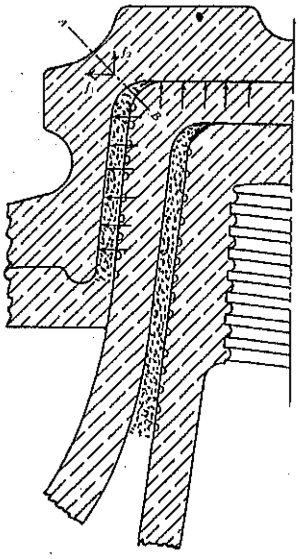

FIG. 2

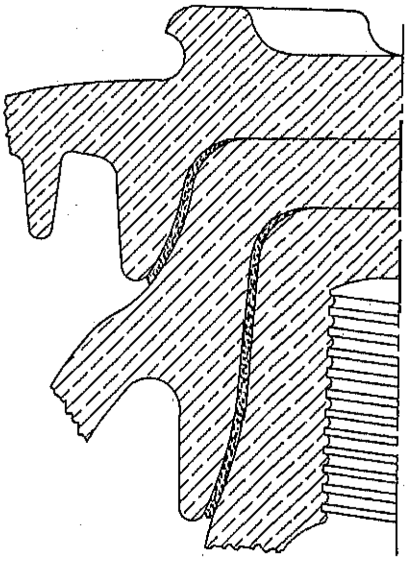

FIG. 3

Owing to deficiency in mechanical strength, European porcelain does not seem to withstand the mechanical stress very satisfactorily, and it has been general practise abroad to avoid cementing, or to use special cements at greatly increased cost.

A microscopic examination of the cement sometimes shows a marked crystalline growth in the cement, particularly where the insulators are near railroad crossings, or in cement exposed to continued weathering.

Fig. 4 is reproduced from a photomicrograph of cement taken from the insulator on the right of Fig. 1. Taken at a magnification of 49 diameters, a few crystal growths are visible. Fig. 5 shows a marked growth in the cement from a strain insulator. These insulators gave trouble in a little over a year, so it is evident that cement expansion played an important part in causing failure.

Fig. 2 shows a section of an ordinary pin-type insulator which usually cracks along the line *AB*. It is readily seen that a contraction of the outer part or expansion from the cement will set up a very high stress along *AB*. As this stress is highly concentrated in most insulators, owing to two components at nearly a right angle, the break often occurs through a very thick part.

The large cement spaces and shape of the insulator greatly increase the hazard or danger of cracking in the insulator shown in Fig. 2. In Fig. 3 is shown one of the later designs of insulators which have proved to be practically proof against lightning and it is evident that the stress set up by uneven heating or cement will not only be less, but the strength of the parts resisting these stresses will be greater.

This type of insulator has low working stresses, so it is possible that high-frequency disturbances which would cause a considerable heating of the cement in the insulator shown in Fig. 2 would have little or no effect on the insulator shown in Fig. 3. Also refinements in cement, or the elimination of a portion of the stress by dipping the ends of the shells in an elastic varnish or wax, or the insertion of a cushion, which would be beneficial in Fig. 2, would be entirely unnecessary in Fig. 3.

The material is so distributed in the later types of insulators that not only are exceedingly high tests obtained on the parts, but a small protecting air path is provided between conductor and pin to act as a safety valve for surges.

Fig. 6 shows an improved insulator, a section of which is shown in Fig. 3, flashing over at 216 kv. for a striking distance of 14 in. (35.5 cm.), and having a total part test of over 300 kv.

There is nothing in practise to show that anything would be gained by increasing the conductivity of the cement in insulators of this type or metallizing the surfaces to reduce heating from flow of charging current under high-frequency surges, although tests on the oscillatory transformer may show that this is beneficial in the ordinary insulator with its high charging current.

Fig. 7 shows typical breaks in two different suspension insulators. On the left is shown a disk with crack in the groove at the shoulder from combined expansion of the cap and cement exposed to weathering. The stress is concentrated by the shape of the insulator and the cement groove. This groove affects the strength somewhat like a scratch in a pane of glass. Insulators may also be cracked slightly at this point by too high mechanical tests or rough handling, although there is no outward sign. The elimination of the cement next to the flange and the substitution of a sanded surface in place of the grooves for holding the cement greatly reduces the maximum stress.

To the right of Fig. 7 is shown a failure in an insulator of similar design but of different material. These insulators have transverse cracks in the bottom of the grooves, showing that the insulators would not withstand the elongation of the metal under the highest working temperature. A higher assembly temperature would improve this or preferably a sanded surface in place of grooves, for the latter would be free from the objection of high shearing stresses in cold weather.

A magnified view of a sanded surface is shown in Fig. 8. In addition to eliminating grooves which tend to concentrate both electrical and mechanical stress, this surface is of equal gripping efficiency in any direction. This latter property greatly reduces the maximum stress set up in insulators working under heavy mechanical loads.

As there are records of insulators working under loads which set up stresses of at least 50 per cent of the ultimate, it seems quite probable that most mechanical failures are due to stresses very much higher than have been thought possible.

It is possible that vibratory stresses which are most severe in dead-end insulators may cause a breakdown of the dielectric structure which, with the greater weathering, may account for the very much poorer showing made by dead-end insulators in some cases.

It is certain that, where the maximum stress is very high and fluctuating with temperature, it will be only a matter of time before the molecular structure of the dielectric will be destroyed. Where this is combined with an increasing stress from cement expansion it is apparent that failures may be very serious in time, although there is little evidence of this during the early years of operation.

While only defects from mechanical stresses have been considered, there are others of an electrical nature that are always present and in many instances are far more serious.

Good porcelain will withstand considerable heat, so material which acts as a resistor may pass electrical tests successfully, only to depreciate very rapidly in service owing to the absorption of water, which greatly lowers the resistance.

Porous material or that which lacks vitrification, while withstanding high voltages at time of installation, gradually loses its ability to carry electrical stress. Where the absorption is slight the insulator may have an appreciable amount of dielectric strength after a number of years, but where the absorption is large there will be little insulation in a year or so. On some of the earlier lines there was a large percentage of porous ware, which accounts for the poor operation until this material was weeded out.

An investigation of one of the large systems showed that out of 2 per cent of insulators shown to be weak by the megger, at least 1.4 per cent were poor owing to lack of vitrification, and could be detected by the trained eye.

Of the remainder, part were defective owing to porous streaks or the developing of faults left by the burning out of lint or other impurities. This really made the percentage of insulators which were poor, owing to conduction, over 1.4 per cent. It was not possible to classify some of the remainder outside of those having failed by cracking.

Fig. 9 shows a small fault detected by the megger and later burned by a very small current.

Porous insulators, while forming by far the largest percentage of defective members in the better designed insulators, can be detected to a large extent by Mr. Gaby's megger method and removed from the line.

For the factory use, it is advisable to use a more sensitive instrument than the megger in order to detect insulators which have very minute defects or are only very slightly deficient in insulation.

Fig. 10 shows a galvanometer which may be worked on a very high direct voltage obtained by rectifying and charging from the peak of the wave. Surface leakage has given considerable trouble, but it is hoped that improved means for shunting this surface leakage current will make this method very valuable.

Failures from electrical stress may be gradual, for it is possible to puncture porcelain several times, where the flow of current is

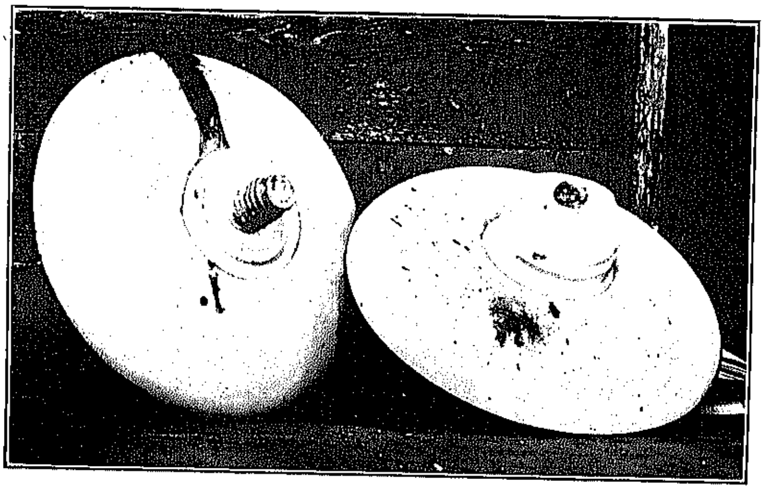

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FIG. 7

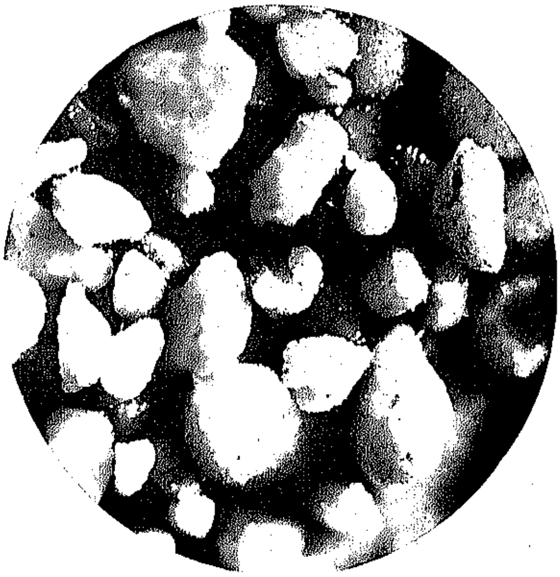

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FIG. 8

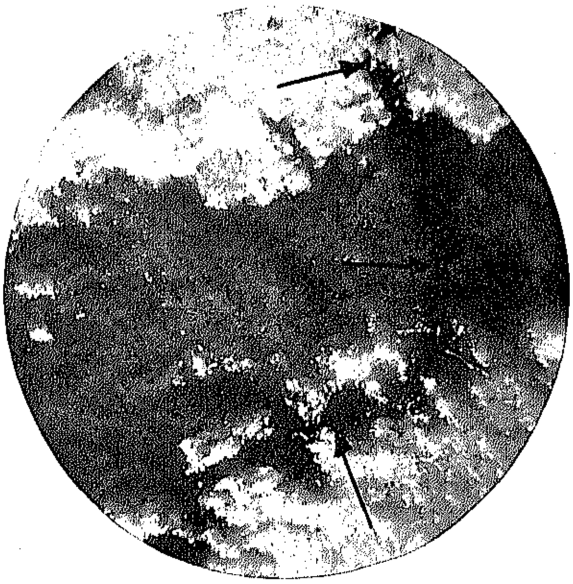

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FIG. 9

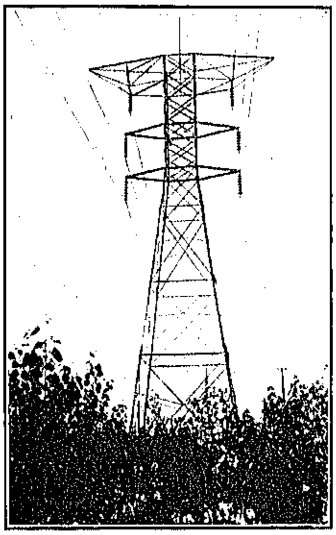

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FIG. 11

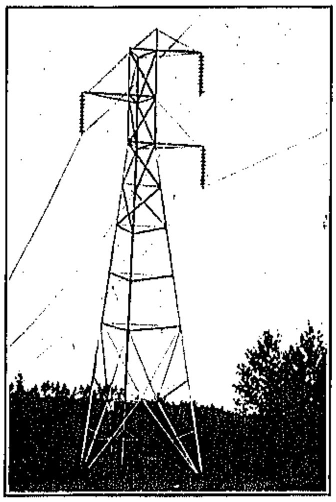

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FIG. 12

extremely small, before complete failure occurs. For this reason surges sometimes do considerable damage to a system and their effect is not noticeable until the cumulative damage causes a complete breakdown.

Since the static breakdown is in the nature of a very slight mechanical fault, it is not surprising that a comparatively low electrical or a mechanical stress will cause complete breakdown in time.

The success of some of the later types of insulators, however, shows that there is little to be feared from static puncture as compared to some of the other defects in the insulator.

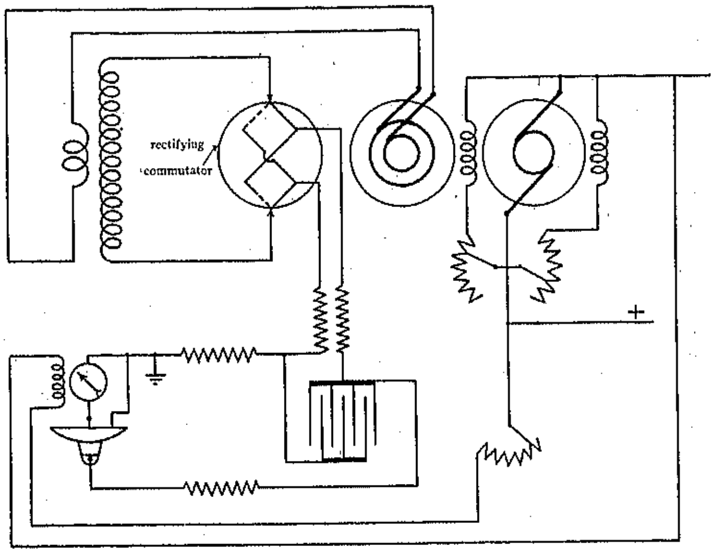

FIG. 10

In well-insulated lines, trouble comes not by the depreciation of the insulators as a whole, but by the matching up of defective parts in a single insulator or string such that the normal voltage or a switching surge causes the insulator to spill over or puncture. Just what the factors governing this are, was not apparent until some recent investigations caused this matter to be investigated and more thoroughly analyzed.

The investigation of some of the systems shows that there is practically no successive breakdown in the insulator, and that faulty members are about equally distributed throughout the string. This, with the total absence of punctures during several years' operation on lines like the Shawinigan Water and Power

Company, Fig. 11, and the 140-kv. Au Sable Electric Company's line, Fig. 12, shows that there is little danger of puncture from high-frequency surges where the insulator is made up of six or more closely spaced, well tested sections.

Lines of this class have also shown that the modern line is practically lightning-proof, for these systems have not averaged one kickout in two years from the spilling of insulators, from lightning or any other cause. This performance has, of course, been much better than was thought possible when the lines were insulated, and shows that spill-overs which have caused so much trouble on some lines can be prevented on a new system at a comparatively low cost for insulation.

The big problem in line insulation is not so much to design for high-frequency but first of all to prevent depreciation as far as possible, or at least to minimize the danger due to matching up of faulty parts in the insulator, for it is evident that if an insulator has a large number of parts which become bad through absorption or cracking, trouble is sure to follow, regardless of the fine showing of an insulator on high-frequency tests.

Since the line trouble on the better insulated lines will come from the matching up of parts in the insulators which have become bad with time, rather than from lack of dielectric strength provided by the design, it is necessary that we recognize these conditions in order that the good operation of the system be maintained or established economically. To this end it is well to consider the probability of trouble from this source and analyze the problem, in order that the relative importance of the factors governing the matching up of the faulty parts to the danger point may be obtained.

Let p = per cent depreciation, or average number of parts bad in 100.

n = number of parts or disks in the insulator or string,

b = number of parts which may be bad in a single string when danger point is reached,

$g = (n - b)$ = number of good parts in insulator when danger point is reached,

P = probability of a string being dangerous,

N = number of strings on the system.

From the theory of probabilities it follows that the probability of all the parts in a given insulator being faulty will then be

$$P = \left(\frac{p}{100}\right)^n \qquad (1)$$

Switching surges, however, will usually spill or puncture several parts, so it is necessary to assume a dangerous condition when only a portion of the insulator is bad. Equation (1) is then important only when the line is insulated with a single part or has not carried voltage.

Where the danger point is reached when there are b parts bad, the probability of a string being dangerous becomes

$$P = \left\{ \left(\frac{p}{100}\right) \left(1 + \frac{g}{b}\right) \right\}^b \qquad (2)$$

The above follows from equation (1), for as we are concerned with the matching up of b units only, n becomes b in the permutation, and as all the units contribute to make up the faulty b members the percentage depreciation must be increased by $\frac{g}{b}$.

Substituting $(n - b)$ for g in (2) gives

$$P = \left\{ \left(\frac{p}{100}\right) \left(1 + \frac{n-b}{b}\right) \right\}^b \qquad (3)$$

$$= \left(\frac{p\,n}{100\,b}\right)^b \qquad (4)$$

In order to obtain the number of dangerous strings or insulators on the system, it is then necessary to multiply P by the total number of strings on the system, or

$$NP = N\left(\frac{p\,n}{100\,b}\right)^b \qquad (5)$$

gives the probable number of dangerous strings on the system.

In Fig. 13 are shown some curves where the minimum insulation is maintained for various number of parts n in the insulator. These curves show that a line having only 2 per cent depreciation and a switching surge that would spill two parts would have 30 dangerous strings in 1000 strings, where there were only three sections in the insulator. The addition of another part, however, reduces this hazard about 95 per cent and the addition of still another part reduces the probable dangerous strings to 0.064 in 1000 strings.

These curves show the economic importance of having a sufficient number of parts in the insulator in order to produce reliability.

Operation bears out these curves, for systems which were under-insulated have been very greatly improved by slightly increasing the insulation.

In Figs. 14 and 15 is shown the effect of varying depreciation for different insulators where the number of parts and minimum possible insulation is constant.

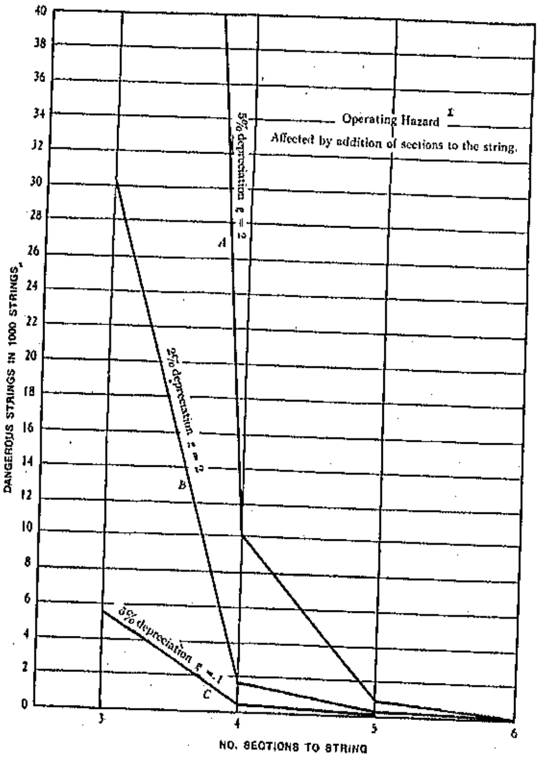

Fig. 13

These curves show that the operating hazard increases very rapidly with the increase in the rate of depreciation, particularly for insulators which have only a small margin above the switching surge. It is also apparent that the reduction in the magnitude of the switching surge which allows an increase in *b* for a given insulator will greatly improve the operation of a system.

This point should not be overlooked, for it is of considerable economic importance, as resistance or reactance in the switch costs but little compared to an increase in the total insulation of the system. The curves also show that the advantage gained by building up the voltage and the elimination of the switching surge should not be underestimated, particularly where the system is having trouble.

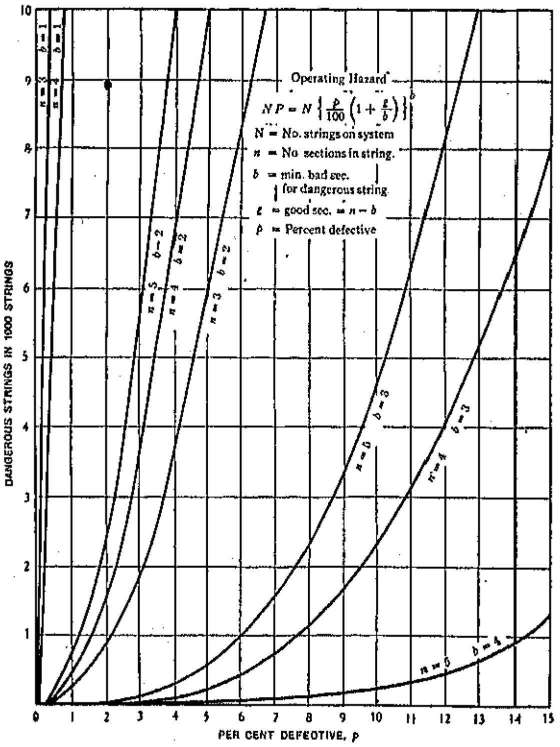

FIG. 14

Space will hardly permit at this time of a thorough discussion of the relative economic importance of the effect of depreciation, number of sections, or the magnitude of switching surge on the reliability of the system, but the curves will give a very good idea of the vast importance of the matching up of defective insulators in producing line trouble.

Where the depreciation is due to porous material, "meggering" of the line will weed out this material and the operation will be greatly improved. If, however, the internal stress in the insulator is high, causing the insulator to fail at an increasing rate through cracking after several years' operation, it is evident that it may become very difficult to maintain the best of operation unless the line is gone over quite frequently. Trouble from the latter will be lessened by distributing new insulation uniformly throughout the different insulator strings.

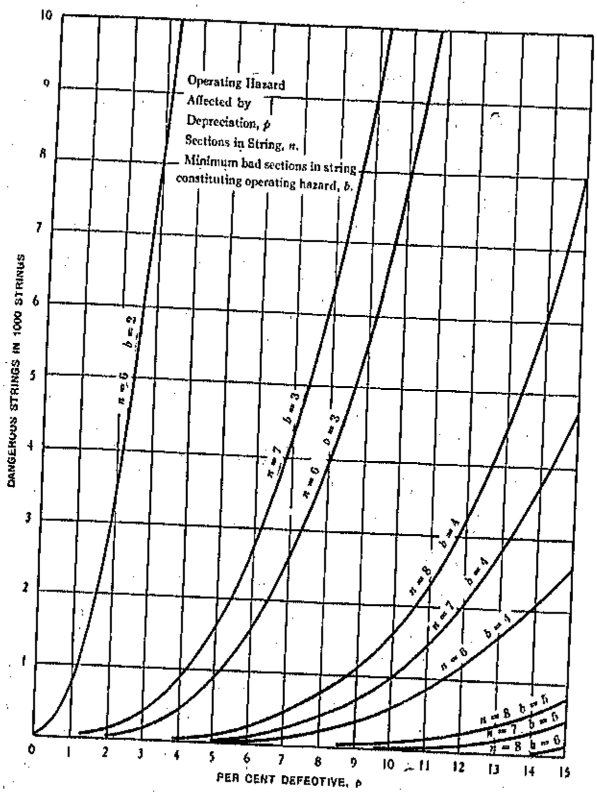

FIG. 15

Since the trouble on the line comes not from the insulator of average strength but from the insulator having the large number of weak members, it is highly important that the characteristics of the weak insulators be given careful consideration.

It must be remembered that even though the insulator is subjected to a flash-over voltage, the probability of failure decreases with the increase in the number of sections in a closely spaced insulator and that a large insulator may operate under very severe

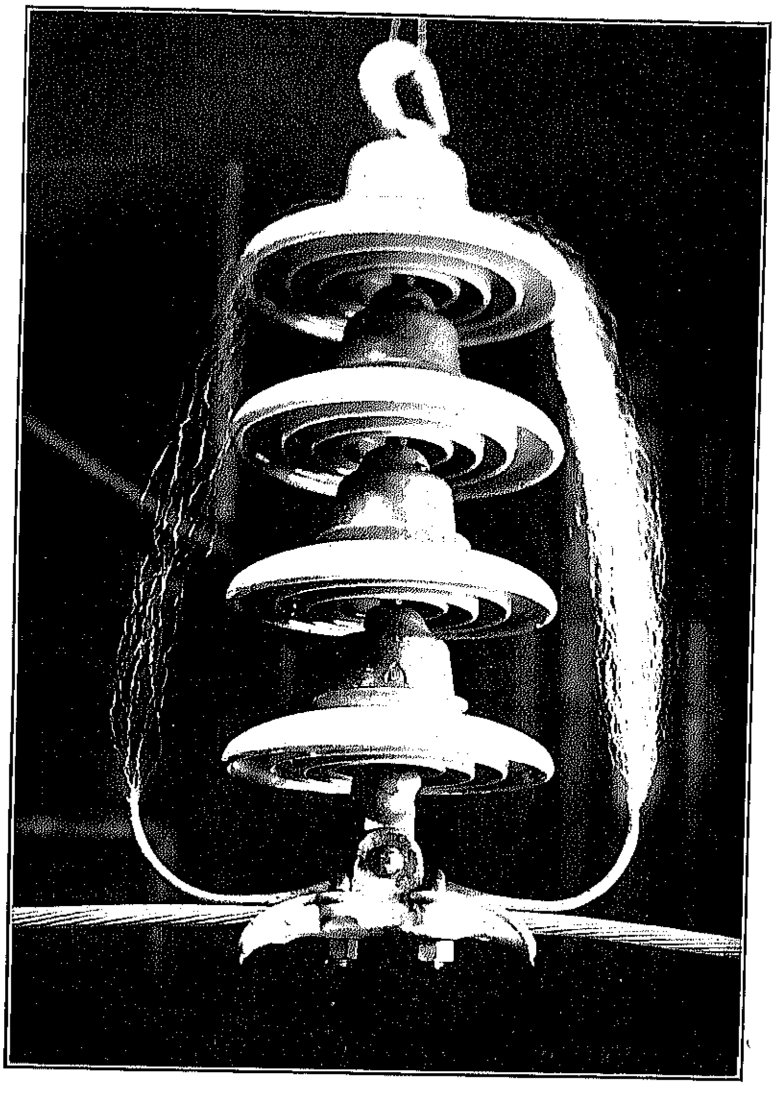

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FIG. 16

conditions, while an insulator composed of a few sections may fail, owing to lack of sufficient factor of safety, although the flashing voltage was much lower.

Since we have plenty of evidence to indicate that there is little to be feared in the large insulator, it is apparent that where failures occur it is usually due to the lack of factor of safety in the remaining good insulators in a string.

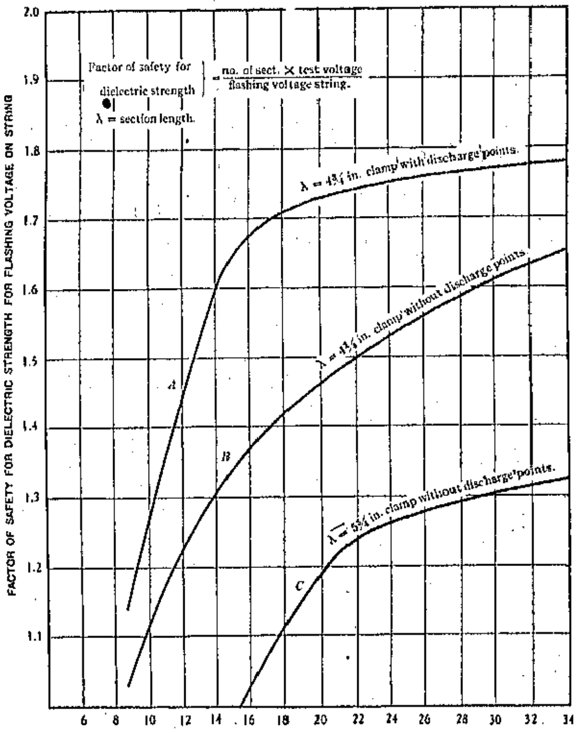

FIG. 17

The use of discharge horns and very closely spaced insulators improves the factor of safety for an insulator having only a few units. The insulator of this type is shown in Fig. 16. Fig. 17 shows curves based on this insulator and it is apparent that while the discharge points on the clamp greatly improve the factor of safety for a few units they do not materially improve the factor of safety for a long string. Since, however, depreciation is likely to reduce the total number of good units in a string, it is advisable to use the discharge points in order that the remaining sections will tend to flash over rather than puncture.

It is not advisable, however, to obtain a very high factor of safety in this way, otherwise there may be too many spill-overs on the line, causing interruptions which may be even more serious than punctures where the discharge points were not used.

It becomes more apparent every day that a transmission line is like a chain in that it is no stronger than its weakest links, and if we are to improve operation we must give the factors governing these weak links proper consideration.

Improved mechanics in the insulator and test methods will do much to improve the reliability and life of future lines, as there seems to be little or no depreciation in the material where there is a good margin of safety.

It must be remembered that even a slight degree of insulator depreciation produces an operating hazard through the matching up of weak parts, and may cause trouble, whereas a much higher degree of depreciation on other parts or apparatus on the system may cause no interruption, nor give any direct evidence, and may be overlooked. Even with the high working stresses set up in the dielectric, it is doubtful if insulator depreciation is much, if any, greater than that of much of the other apparatus on the system, and attention to the factors causing trouble through depreciation will do much to improve operation of present or future systems.

DISCUSSION ON "EFFECT OF ALTITUDE ON THE SPARK-OVER VOLTAGES OF BUSHINGS, LEADS AND INSULATORS" (PEEK), AND "INSULATOR DEPRECIATION AND EFFECT ON OPERATION" (AUSTIN), NEW YORK, DECEMBER 11, 1914.

Harvey L. Curtis: For many years it has been known that there may be considerable leakage over the surface of insulators. However, it is only within a comparatively short time that quantitative measurements have been made. The present investigation* was undertaken to determine the conditions under which leakage would become troublesome in the use of electrical instruments. It has been extended to cover a considerable number of insulators; and for these the effects of temperature, humidity, voltage and exposure to light were studied.

The samples of materials were obtained, whenever possible, in plates 10 cm. square by 1 cm. thick. Metal strips 1 cm. wide were clamped to this with their adjacent edges 1 cm. apart, as shown in Fig. 1. The resistance was measured between strips *A* and strips *B*. The surface resistivity is assumed to be twenty times the resistance measured. While this is not strictly true, since there is leakage over the edges as well as over the face of the specimen, yet the correction is too small to take account of in the present work. To insure good contact, tinfoil was wrapped around the metal strips and carefully pressed against the surface of the insulator along the inside edge of each strip.

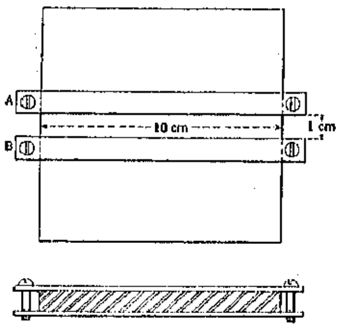

FIG. 1

To determine the effect of temperature and humidity it was necessary to place the samples in a case, the temperature and humidity of which could be maintained constant. The temperature was maintained constant by a vapor pressure thermostat. The humidity was regulated by placing in the case an open vessel containing a sulphuric acid solution of the proper strength to give the desired humidity. The air was thoroughly stirred by an eight-inch fan, the driving motor being outside of the case. The leads to the specimens were brought out through blocks of paraffin on the top of the case. These were melted together, so that the case was sealed almost air-tight. A glass window permitted the reading of the temperature and humidity.

The humidity was measured by determining the temperature at which dew would form on a polished metal surface. The deposit of dew was usually obtained by circulating cold water through a metal tube, but for very low humidities it was found necessary to use alcohol in the tube and cool it by adding carbon dioxide snow.

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*A paper, entitled "The Insulating Properties of Solid Dielectrics," has been published as Scientific Paper No. 234 of the Bureau of Standards.

In measuring the resistance, high accuracy was not required. An accuracy of 10 per cent was considered sufficient. As a large number of samples were measured, and each sample measured several times, it was necessary to arrange the apparatus so that it could be worked rapidly. To do this a condenser of suitable capacity was connected in parallel with a sensitive galvanometer. The galvanometer, which had a wide range of shunts, was placed directly in the circuit with the battery and resistance to be measured. If the current was sufficient to produce a readable deflection, the galvanometer was used as an ammeter. If the current was so small that it could not be read on the galvanometer, the galvanometer only was taken out of circuit, and the current which flowed over the surface of the specimen, was collected on the condenser. After a known interval of time the galvanometer was again connected, so that the charge which had accumulated on the condenser was discharged through the galvanometer. From the time of leakage, the voltage of the battery, and the constant and deflection of the galvanometer, the resistance can be computed.

The current which flows between two conductors, maintained at different potentials and insulated from each other by a solid material, is made up of two parts; that which flows through the insulator proper, and that which flows through a film of moisture or other conducting material on the surface of the insulator. The relative importance of these will depend on the resistance of the two paths. Since water, even if very pure, conducts much better than the ordinary solid insulators, a very thin film of water may have much less resistance than the insulator.

Before discussing these further, some definitions are desirable. The volume resistivity, ρ, of a material is defined as the resistance between two opposite faces of a centimeter cube. From the relationship between the size and the resistance of a specimen it follows that

$$R = \frac{\rho l}{A} \text{ or } \rho = \frac{RA}{l}$$

where R is the resistance of a cylinder of cross-section A and length l. By analogy we shall define the surface resistivity as the resistance between two opposite edges of a surface film which is one centimeter square. If the film is uniform over a surface

$$\sigma = \frac{R'b}{l}$$

where σ is the surface resistivity and R' the resistance of a rectangle of the film of length l and breadth b.

Since our measurements show that the surface film is largely moisture condensed from the surrounding atmosphere, the atmospheric humidity will largely determine the surface resistivity of a material. However, it is to be expected that the temperature of the specimen will be of some influence. Also since chemical changes are often produced by exposure to light, the surface resistivity of a material may be affected by such an exposure.

It might be expected that the applied voltage would affect the surface resistance, but, though voltages from 2 to 200 were used in some cases, no change in resistance was observed. At high humidities the resistance frequently changed by as much as a factor of 10 in the first minute after closing the key—increasing with some samples, decreasing with others. No cause for this behavior has been found. The value at the end of one minute has been taken as the correct value.

The results of our experimental work show that, for practical work in the laboratory, changes in surface leakage due to changes in temperature are of so little importance compared to the changes in resistance due to changes in relative humidity that they may be neglected. It is not to be supposed that this will hold for temperatures considerably removed from those used in this investigation; viz. 20 to 30 deg. cent.

In order to determine the effect of humidity upon the surface resistance, a number of samples were placed in the case whose temperature and humidity could be controlled. Measurements of the resistance were then made, but with an interval of at least one day after each change of humidity. After computing and tabulating the results, a curve was plotted for each sample showing its change of surface resistivity with the humidity. Nearly two hundred such curves have been plotted. From these, the curves given at the end of this discussion were selected.

Except in a few cases where it was desired to show the effect of cleaning, the samples were cleaned in the same manner and to the same extent as would be done in practical work; *i.e.*, they were wiped with a cloth or dusted with a brush.

All of the curves of surface resistivity are plotted on the same scale, so that they can be readily compared. In order to make this possible, the logarithm of the surface resistivity is plotted as ordinate, so that the actual values of the surface resistivity progress by powers of 10. In this manner very large changes of resistance can be shown on one sheet. The abscissa is the per cent of relative humidity.

Exposure to light may produce a chemical change at or near the surface. This chemical change may change the appearance of the material as well as the surface resistivity. However, there does not appear to be any connection between the two. Some samples, which show a very pronounced change in appearance, show very little change in surface resistivity, and the reverse is sometimes the case. As the chemical changes produced by sunlight take place very slowly, the number of specimens examined has been limited. The major portion of the work has been done upon hard rubber, where the changes take place rather rapidly.

In Fig. 2 is a curve showing the change in surface resistance of a sample of hard rubber which was exposed to sunlight. In July 1908 the sample, which had deteriorated, was cleaned by washing in distilled water. This restored it to its original value, but the deterioration again proceeded rapidly.

The deterioration of some other materials when exposed to sunlight has been studied. In general it may be said that in no case is the deterioration as rapid as in the case of hard rubber. In some cases no effect has been observed.

In conclusion it may be stated that the surface leakage of the majority of materials varies greatly with the humidity of the surrounding air. This is due to the film of moisture which is condensed upon the surface. Any condition which, at a given humidity, will decrease the condensation of moisture or which will decrease the conductivity of the water will increase the surface resistance.

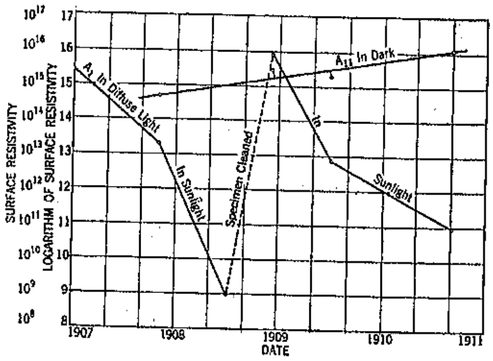

FIG. 2

In Fig. 3 are given curves of four samples of hard rubber. Two had been protected from the action of the light, while two had been exposed to strong sunlight for several months. It will be noticed that between 0 and 50 per cent humidity the new rubber changes but little, while above that the changes are very pronounced. The surface resistivity is one *million* times as large at 50 per cent humidity as at 90 per cent. With the rubber which had been exposed to the light the changes in resistance continue until the lowest humidity is reached. The resistance of these specimens at very low humidity is 10^{11} times or one hundred billion times as great as is the resistance at

95 per cent humidity. It will be seen that very slight changes of the humidity will affect the insulation in a very marked manner.

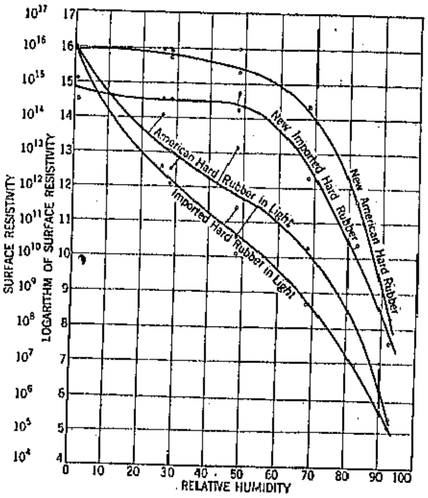

Fig. 3

Other samples of hard rubber have been tested, and those given may be taken as representative of the best grades of hard rubber. Of the two kinds whose curves are given, the imported rubber has a finer texture, and can be worked and polished

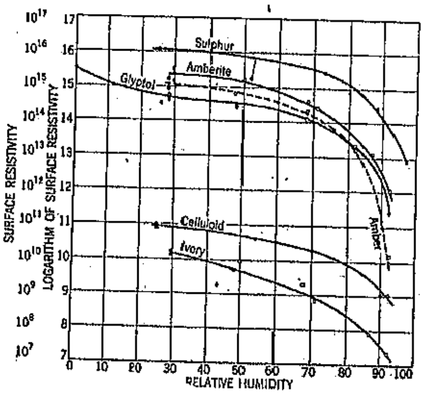

Fig. 4

better than the American rubber. However, all the tests upon the insulation show that the American rubber is the better insulator. This shows how difficult it is to connect the insulating properties with the mechanical properties.

Three of the curves given in Fig. 4 are for amber and amber-like materials. The sample of amber was a piece of clear native amber, the surface of which had been carefully polished. This is one of the few cases where only a single sample was measured. The amberite was a sample of the material which is made by compressing scrap amber. This material under the name of amberite or ambroid is now extensively used and it is apparent that so far as surface leakage is concerned it is the equal of native amber. In working with this material it was found that the specimen must be well cleaned to get the best results. Apparently handling with the fingers leaves a deposit of various deliquescent salts which condense moisture and lower the conductivity at the higher humidities. The glyptol is an artificial resin, resembling amber.

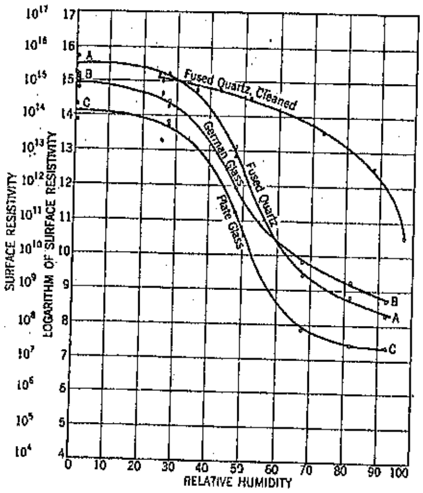

FIG. 5

Three different samples of sulphur were tested. They showed wide variations. The curve which is given lay between those of the other samples. Threlfall states that sulphur heated just to its melting point and then cooled has better insulating properties than that which has been heated to a higher temperature before cooling. The sample of celluloid was a piece of clear celluloid. Several samples were tested having various amounts of coloring matter and filler, but the surface resistivity was substantially the same for all. Ivory can not be considered as a material having high insulating properties. A substitute, white galalith, is somewhat better.

In Fig. 5 the behavior of fused quartz and certain kinds of ordinary glass is shown. Several samples of quartz were tested, but the two curves given were for the same sample. The sample from which the curve marked "fused quartz" was obtained was cleaned in the same manner as other samples, but no special care was taken. It was then carefully cleaned in strong chromic acid, washed in distilled water, and dried before obtaining the curve marked "fused quartz, cleaned." The surface was thus well freed from foreign substances. At low humidities there was no difference in the two specimens. At higher humidities there was a large difference, amounting to as much as a factor of ten thousand. This may be due to the lack of condensation of moisture on the cleaned specimen or to the fact that the water which is condensed has a lower conductivity. Doubtless both of these causes play a part.

The statement is sometimes made that the method of manufacture of fused quartz very decidedly affects the insulating properties of the product. This has not been substantiated by the results obtained in the course of this investigation.

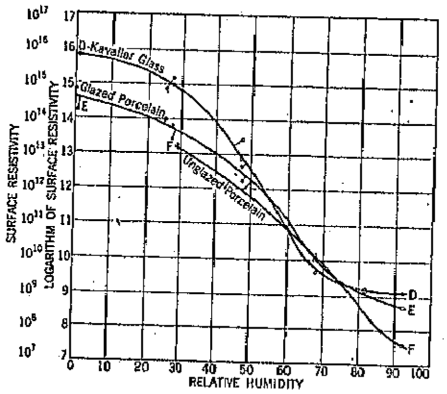

FIG. 6

A piece of old quartz tubing made by Heraeus in 1904 was measured at the same time and under the same conditions as the sample marked "quartz, cleaned." The results were practically identical. Another sample of inferior manufacture gave, under the same conditions, the same results as given by the curve marked "fused quartz."

The curves for three kinds of glass are given in Figs. 5 and 6. The Kavalier glass is a very hard combustion tubing having a large potassium and calcium content and a small amount of sodium. The German glass is a soft glass tubing such as is usually used in glass blowing. The plate glass was a piece from a plate-glass window. It will be noticed that the curves fall very sharply at about 30 per cent humidity, and that above 70 per cent humidity the change is not so marked. These samples were tested twice, with the results as given. Later they were cleaned with chromic acid in the manner described for quartz and the resistances measured a third time. While the results did not show such marked changes as in the case of quartz, they were all in the same direction. Also the effect was most pronounced on the hard Kavalier glass and least so on the plate glass. It is known that the Kavalier glass is less soluble* than the other forms. Hence it is quite probable that the difference may largely be due to the difference in the conductivity of the water solution on the surface.

In Fig. 6 are also given curves for glazed and unglazed porcelain. The glazed porcelain was the base of a small porcelain switch, while the unglazed was a plate such as is used in chemical work.

In Fig. 7 are grouped the curves of some of the poorer insulators, together with some curves showing the effect of impregnating them with paraffin. The slate was taken from the base of a switch and its origin is not known. The source of the marbles is stated on the curves. All were free from metallic veins, and were the equal of any that are used in switchboard construction. It appears that the coloring material in the Vermont and Tennessee marbles has very little effect on the surface leakage.

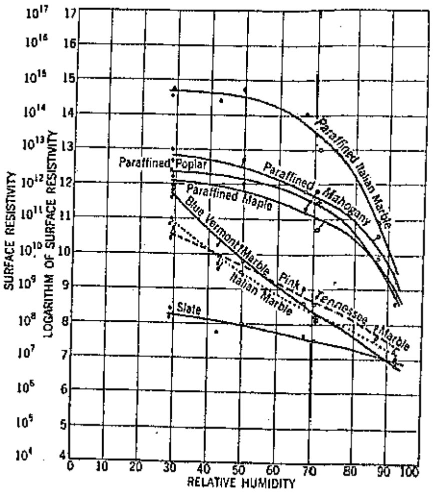

FIG. 7

The marble and the different varieties of wood were impregnated with paraffin by keeping them in molten paraffin until no more air bubbles were given off. After cooling, the wood was planed and the marble sandpapered so that the resistance was measured over a surface of wood or marble with praffin filling the pores and not over a layer of paraffin on the surface.

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*Hovestadt: Jena glass, p. 333.

The woods of more open grain, such as mahogany and poplar, show a somewhat higher insulation than the closer-grained maple.

The paraffined marble shows the considerable increase in the insulation that may be obtained by impregnating with paraffin. The surface does not present as clear and pleasing appearance as before paraffining, and it accumulates dust more readily. The marked decrease of the resistance with increasing humidity is not readily explained. One would expect that it would behave more like paraffin, which shows little change.

In Fig. 8 are given curves for various waxy materials. Ceresin is refined from the mineral ozokerite. It somewhat resembles paraffin, but has a higher melting point (69 deg.). An attempt was made to measure the leakage resistance of a sample at several humidities by the galvanometer method, using a distance of 1 mm. between the plates. It was impossible to obtain a readable deflection, but it is certain the values are above those given in the curve. With the electrometer method the surface resistivity was still too high to measure, certainly above 10^{18} ohms. A special paraffin having a melting point of 58 deg. cent. also gave results too high to measure by any method at our disposal. A commercial form of paraffin known as parowax (melting point 52 deg.) gave the results shown in the curve. Measurements by the electrometer method gave a satisfactory check on these results.

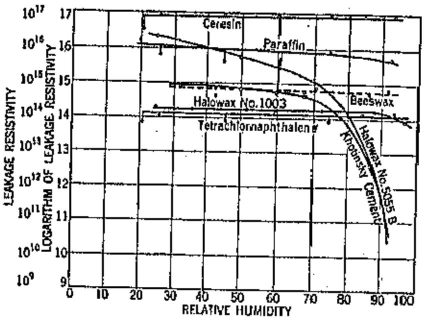

FIG. 8

The curve for beeswax was obtained from a sample of the yellow, unrefined material. White beeswax gave results which are almost identical. For these materials the surface must be fresh. They deteriorate quite rapidly when exposed to light and moisture.

The sample of tetrachlornaphthalene was furnished by Dr. Baekeland. It is doubtless a mixture of several isomers and may contain other chlorinated naphthalenes. It is about the consistency and color of yellow beeswax and has a very characteristic odor. The samples of "halowax" are chlorinated naphthalenes. The sample No. 1003 is largely tetrachlornaphthalene. It is of a gray color, but in other respects has much the same properties, including odor, as the sample furnished by Dr. Baekeland. The sample 5055B is a higher chlorinated naphthalene, being largely hexachlornaphthalene.

The Khotinsky cement was flowed on a glass plate. The thickness was such that no appreciable part of the current flowed through the glass.

These waxy materials show the least change with humidity of any of the substances tested. This is doubtless due to the fact that the water does not wet the surface, hence instead of spreading over the surface is collected in minute drops.

D. B. Rushmore: In my opinion, the problem of insulator design must be solved by a scientific study of cement and a scientific study of porcelain; and by analyzing the elements, as we have in other problems, we will find out what is taking place, but the problem of measuring the causes of the trouble and knowing just what the surges are, in knowing just what the electrical forces are, and also in knowing just what are the physical conditions of the resistance opposed to these forces, is very difficult. Probably there is no other field of engineering in which it is so hard to get at these quantities with exactness.

I was very much impressed with the analogy of porcelain design to the design of delicate steel castings, and it was evident in some of the insulators that have been shown on the screen that, if casting these pieces of certain qualities of steel, the lines would have to be modified to prevent the undesirable forms of crystallization.

There is one thing that is closely related to the study of insulator application, and that is the practical necessity, both from an engineering and a commercial standpoint, of determining quantitatively the value of a ground wire. That has not yet been done, hundreds of thousands of dollars are spent every year in installing ground wires, and nobody knows of just how much value they are, and this cannot be determined by practical experience. It must be the result of the same kind of investigation that has solved the corona problem, and that, as Mr. Curtis has shown in the method he has worked out, must be by understanding the problem of surface leakage.

E. D. Eby: These data are not only interesting, but vitally important. They affect the design and operation of all electrical apparatus dependent upon air as an insulation. The "law of corona" was given to us some time ago, but the probable corresponding law for spark-over has not been generally appreciated.

Since the local corona point varies directly with the density, and the spark-over voltage approximately with the density, it appears that the same relative performance will occur at all densities. Therefore, an altitude rating is logical, safe and necessary. This was found desirable by the speaker about two years ago in connection with transformer bushings, and has been applied in his practise since that time. The altitudes to be considered seldom exceed 10,000 ft. Several important installations exist at 4000 to 5000 ft.; a dividing line was set at 4000 ft., below which leads rated for 4000 ft. are supplied, and above which leads rated for 10,000 ft. are supplied.

In the cases of the leads which Mr. Peek has tested, the departure of the correction factor from δ amounts to as much as 15 per cent of δ at $\delta = 0.50$. This would be worth considering, as it represents a fair margin between factory test voltage and spark-over. But, since 10,000 ft. is the maximum altitude reached, except in very rare instances, the departure of the correction factor from δ (6 or 7 per cent) at that altitude is not worth considering, beyond treating it as an additional margin of safety.

An interesting detail of the tests on suspension insulators is the wide departure of the correction factor from δ in the case of one unit, amounting to 44 per cent at $\delta = 0.50$ in Table IV, compared with the close agreement in the case of two-, three- or four-unit strings. Perhaps Mr. Peek can add some explanations to these figures.

In putting into practical application the information given in this paper, it must be remembered that these tests were made at 60 cycles, and consequently are valuable chiefly in the degree in which they represent high-frequency performance. With the usual factors of safety in the design of leads, bushings and insulators, nominal frequency voltages would seldom, if ever, tax well-designed apparatus to the spark-over point of maximum elevation. It is, therefore, of primary importance that these data should apply to high-frequency voltage. It is known that different designs of leads and insulators perform differently under high frequency. Whether such differences may be expected to affect the altitude factor, perhaps Mr. Peek can tell us.

P. W. Sothman: Every time this very vital subject of insulation is touched upon, we are apt to have the feeling that we are getting further away from it, and I was afraid to-night that Mr. Austin might again change my mind in regard to certain conceptions I have had, but in many points I agree absolutely with Mr. Austin, particularly that, from a mere investigating standpoint, we should learn how to build an insulator. We have tried to teach and preach for the last few years that the insulator is one of the most important elements in the whole system; that it is as important as the generator or lightning protection, or a switch or anything else; still an insulator is chosen, because it will do a certain thing in a certain district, and it is assumed that it will do the same thing in another district, but, as Mr. Peek has pointed out, what it will do in New York it will not do in Denver.

In that respect I was very much pleased to see that Mr. Peek found a way of expressing to us here tonight, that the actual difference in altitude has an important effect on the insulator, and I think that anybody who has gone through Mr. Peek's paper will see, as short as the paper is, and although it has been condensed to a very great degree, that the data given in it mean an immense amount of labor, and these two papers coming together this evening give us much light on the subject we are considering.

When we take the tests which have been made on insulators in the factory, and then consider the insulators which have failed out on the line, we see that we are absolutely unable to produce the same conditions, in our laboratory, no matter how we try, which agree with the conditions found in normal operation. We are trying to make high-frequency tests. We test an insulator at 25,000 or 50,000 volts, and then we raise the voltage higher and higher, until the child is killed, so to speak, and then we are satisfied. We think that the more power we can force through an insulator without apparent damage the better the insulator we get, but still we find in the case of insulators which will withstand a test, say, of 200,000 volts, in the laboratory, that when we take these same insulators and put them into actual service on a line which is carrying an operating voltage of say 50,000 volts, they will fail the next day, notwithstanding in our laboratory tests we considered them the best insulators that were ever made.

Now, gentlemen, that shows it is not the insulator, as such, that we have to blame for this condition, but there are other elements to which we must look for an explanation of this trouble. Mainly it is the line. There are a number of elements involved, and the insulator is only one of them, important, yet small. If we should build all parts of the transmission line in the way they should be built, we would see that the present factor of safety of the insulator, which is a very high one at the present time, is better than in some of the other elements which are used in the transmission line.

There is one thing which is very gratifying to see, and that is that the porcelain manufacturers have actually made very great improvements in the quality of the porcelain which they produce—I would not say the insulators—but in the manufacture of porcelain they have made very great progress. When we recall how insulators stood up five years ago under what was considered at that time a very severe test, and we see how they stand up today, we conclude that we have learned at least how to make porcelain which will serve the purpose. It is very gratifying, but I would like these gentlemen to get a little busier still, and let them try to make still further improvements; and what strikes me forcibly is that we still find that the porcelain which is imported from Europe is in many respects ahead of our porcelain which is manufactured here.

When three or four years ago we were talking about the percentage of failures—which matter Mr. Austin has referred to in a very interesting manner in his tables—we found that the failures were pretty close to forty-eight per cent, whereas today the same kind of failures amount to more nearly 6 or 7 per cent. I think if the transmission line engineers would cooperate with the porcelain manufacturers, and give them freely their observations, that we could still make substantial improvement in these conditions.

That brings up another point, and that has to do with these specifications for the insulator, as such. We are on the eve of determining whether we shall or shall not make specifications for the insulators, and in that connection I cannot urge you too strongly to be very careful, and I might even caution you to go very slowly, in adopting any rule in which so many phenomena are still involved, which phenomena are so little understood by so many of our practising engineers. There is danger that we may put into a law on this subject a great many things which may be a great handicap to the future development of the insulator.

Selby Haar: I ask Mr. Austin what his opinion is of the nature in which electrical and mechanical stresses in the strain insulator combine. Is it something like the different kinds of mechanical stresses in material, or is it something entirely different?

The reason I ask this question is that I have heard it denied in all seriousness that a strain insulator need necessarily consist of any more sections than an ordinary insulator.

Charles P. Steinmetz: We must not lose sight of the fact that, after all, the line insulator today is really in a very good condition. For many years the line insulator was the weakest link in our transmission system. It is not so today. It is rather one of the strongest links, as shown by great increase of breakdown in all other parts of the system, which formerly were protected by the line insulator failing, thus protecting the other apparatus. This is proper, because it is desirable that the line should be the last thing to break down. Breakdown in a station can be watched for, and can be located, but it is a more serious matter to have a breakdown out on a mountain peak, and then to have to hunt for it in the winter time, during snowstorms, etc.

The problem, then, is really not so much to improve the line insulator—although naturally we expect improvement—as to make sure that the insulator as it exists on the line gives as good results as possible for first-class regulation and maintenance of the insulator protection; in other words, there should be proper testing of the line insulators, and weeding out defective ones. The strains on the insulator are partly electrical strains and partly mechanical strains and that means testing them both for electrical and mechanical strains. From the electrical point of view the problem is, after all, a simpler one, for, although electrical engineering is much younger than mechanical engineering, the method of testing and the various operations are so much more accurate, that we can determine certain things with accuracy in matters electrical. Naturally, the condition of testing should be to test as nearly as possible under such conditions of electrical stresses, etc., as break down the insulators on the line. We all realize that the normal line voltage and normal line frequency practically never break down the insulator, but that it is caused by very high frequency or sudden impulse, or combinations of both; and investigation shows that very often a high-frequency wave train is preceded by a single still higher impulse; thus, high frequency and impulse tests are needed.

While high-frequency testing has been recommended many times, it has one serious danger, namely, that most methods of producing high-frequency oscillations involve the use of electrical resonance, which does not give a definite, but an indefinite, voltage and constant current effect, and it is, therefore, only a question of the power back of it whether you will break down anything or not. Therefore, while high frequency is that method of testing most nearly representing actual operating conditions, it must be made by high-frequency oscillating current generators which give a definite and determinable voltage, and not by the use of resonance to raise the high-frequency voltage to some unknown quantity, determined by the strength of the apparatus, in which case the tests mean nothing. I refer to this latter method because it is the reason for most of the objection which has just been raised against promiscuous testing by high frequency. The proper method involves high frequency produced at definite and measurable voltage.

Not so favorable are the conditions for making the mechanical test. To some extent the mechanical quality can be determined by electrical testing. As has been pointed out in the papers, a test for porosity of the porcelain can very often be determined by resistance measurements. Experience has shown that a more reliable method in picking out mechanical defects such as flaws, porosity, etc., since it does not depend on the effect of humidity, is the use of high frequency for testing.

Unfortunately, there still remain the mechanical strains in the insulator, which may and do, as has been shown in Mr. Austin's paper, break down the insulators either immediately or through rapid deterioration, which the electrical test does not always show, and for which reliable mechanical tests have not yet been devised.

As you probably know, for some years great advantage has been derived from use of the polariscope and polarized light to test for mechanical strains glass apparatus used for electrical purposes. Sometime possibly a similar method may be developed of using light in some form or radiation by which porcelain will be made transparent—X-rays, or some similar process—and show by polarization the internal strains of the porcelain, but we do not have that at the present time.

Assuming that we have reasonably safe methods of eliminating defective insulators, there remains the depreciation to be taken care of, which is to some extent accomplished by a careful study of the design and performance of the insulator, the material of which it is made, and the method of its application.

The reliability of service given by the transmission line, as you have seen from this paper, depends upon, and can very greatly be increased by an increase of the number of units, that is, an increase of the factor of safety. The increase of reliability is greatly out of proportion to the increased margin of safety, because it is not the effect of the margin, but the probability law, which makes it much more improbable in the case of individual insulators that their strength will fall below the stress.

The second method described of increasing the reliability is to reduce the surging. The third method is to reduce the depreciation.

There is really a fourth method, which has not been referred to in the paper, and is in reality included in the last one, or reduction of depreciation, namely, weeding out insulators on the line which become defective. If there is a ten per cent depreciation in five years, by testing the insulators on the line once a year, three-quarters, say, of those which have deteriorated, can be weeded out and the average depreciation will be reduced to a small fraction of what it would have been, if all those insulators had been left in the line; this would, therefore, greatly increase the reliability of service.

That brings us to one requirement which is very badly needed, and that is, reliable methods of testing the insulators on the line without taking them down; preferably, although it is not always essential, without taking the voltage off the line. Such methods would be principally valuable in high-frequency tests, because while in the case of high frequency we deal with considerable power, we do not have to guard against leakage by moisture, as in resistance measurements, and it appears advisable to make systematic tests of the insulators on the transmission lines, just as such tests of underground cables are made, by testing the insulators, disk after disk, insulator after insulator, at fixed intervals, and thereby detect and weed out those which have deteriorated. This method would greatly increase the reliability of operation.

E. E. F. Creighton: Mr. Peek has again added another element to his work on corona and Mr. Austin has not only described some valuable methods but has given us a new design of insulator.

Among the several things I should like to bring up regarding Mr. Austin's paper is, first of all, the sanding of the surfaces of the insulator to give the cement a grip on them. There is a very difficult problem involved in preventing the breakage of the insulators by the cement. If this very simple method is a solution of this problem it will mean a great advance in the production of good insulators.

Many tests on the chunky insulator in Mr. Austin's illustrations show a considerable advance in the design of insulators. Even at high frequency the design is such as to overcome, to a very great extent, the creepage spark. The spark creeps down over the upper surface of the porcelain, but has little tendency to follow the surfaces of the skirts, but jumps directly to the pin. This is an indication of better design in the insulator, as it is less liable to fail.

Before closing, I want to mention the relative values of the methods of testing, among them the megger, which was used, I think, first by Mr. Gaby, in Canada. The megger gives good results where moisture can enter in the crack that is produced. If the crack does not extend all the way through the porcelain the megger is useless. If the moisture is dried out, as it usually is in pin type insulators, it is also useless. I have made tests first with the megger and then with high frequency, which showed that the megger results agreed closely with the high frequency results when moisture in the fault was present.

The direct-current test at high voltages which Mr. Austin mentions I have also used a number of times without any very great amount of success. We have gone at it with rectified currents at very high values of potential, but the trouble is that the air itself begins to leak and the current through the air is so great as to make the leakage through the insulator negligible. It is not the leakage over the surface of the porcelain, because the same leakage takes place when the insulator is removed. This method of test is of value only in special studies.

The third method, which I have had occasion to speak of several times, is the use of the high-frequency transformer. No matter if the fault is due to underfired porous porcelain, or whether there is a tiny flaw somewhere in it, the high frequency will bombard the air in the internal part and will develop these flaws. At the same time the high frequency, properly applied, is quite harmless to good porcelain. In testing porcelains the flaws are weeded out during the first few minutes, or very often in the first few seconds, and then the test can be carried on for fifty hours continuously without any more failures.

Farley Osgood: Mr. Austin brought out the fact that the value of the overhead ground wire should be considered in insulating the line, and he put that value in your minds only from the insulating and protecting standpoint.

I wish to put into your minds the fact that the overhead ground wire has a very distinct value in assisting in the locating of defective insulators, and that in making calculations on the construction cost of transmission lines, you should take that particular point into your calculations, and not consider the value of the overhead ground wire wholly from an insulating or protecting standpoint.

Our experience leads us to believe that the overhead ground wire is worth more as an aid to the operation of the line than it is as a protective device, and by its use, with the proper test instruments behind it, faulty insulators can be located within a few spans, and sometimes exactly, which fact is especially helpful for operating companies whose practise is to test out lines with a view to locating faults and curing them when the lines can be relieved from actual service. The cost of an overhead ground wire of stranded steel or copper-covered steel will, in most cases, be a little more than one of the phase wires of the transmission circuit, assuming the phase wire not to be in excess of 250,000 cir. mils.

F. W. Peek, Jr.: I agree with Mr. Austin that most insulator failures occur due to small cracks in the porcelain caused by local mechanical stresses. These local stresses may be due to expansion of cement or metal parts, improper shaping of porcelain parts, etc. The so-called deterioration of porcelain is due to the gradual formation of these cracks. Electrical failure is finally the result. The following test, to show the above, may be given as an example: Six insulators, all of the same porcelain, but of different designs, were tested with 60-cycle, and with oscillatory voltages. Electrically they were excellent. These insulators were then placed in ice-water for one hour. This water was heated at the rate of 1 deg. a minute to the boiling point; it was then slowly cooled at the rate of 1 deg. a minute to room temperature. Cracks appeared in four insulators due to mechanical stress. Electrical failure occurred immediately upon application of voltage to these four units. The other two were not affected. They were then given a more severe test. They were put in water, which was gradually heated to the boiling point, and were then immediately plunged into ice-water. One failed, while the other remained intact. These two insulators were of the best mechanical design of the lot.

Other causes of failure, due to design and manufacture, are caused by occasional impurities getting into the mixture, porous porcelain, effects of tool marks on difficult designs, etc.

In selecting an insulator it is important: (1) to see that the mechanical design is such that local mechanical stresses cannot result and gradually produce cracking; (2) to see that the electrical design is such that local electrical stress tending to produce puncture will not result; (3) to see that the porcelain is not too porous and that the product is uniform. (1) and (2) are best determined by design tests, such as the one outlined here, and others which have been described in the A. I. E. E. PROCEEDINGS.* (3) is best determined by watching the product very closely in the process of manufacture. If the per cent loss in the routine test is large, or varies greatly, the product may be looked upon as suspicious and should be condemned until the cause of the failures is found. This per cent loss will not only be a check upon the quality of the porcelain but also, to some extent, upon design. For instance, if the design is so difficult that a large percentage of failures results in its manufacture, it should be condemned. I know of insulators that have been selected on a basis of per cent loss on one of the very high-voltage lines which have given practically no trouble.

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* A. I. E. E. TRANS., this volume, p. 1107.

So far, only troubles due to design and manufacture have been discussed. Starting with *good insulators* operating trouble due to their improper use may result. An insufficient number of units in the case of the suspension insulator, or an insufficient "factor of safety" in the case of the pin type insulator, may cause trouble. At each high over-voltage lightning impulse, or high over-voltage surge impulse, an insulator may be damaged by local cracks forming in the porcelain. A puncture is started but has not sufficient time to develop; failure will result only after a number of impulses. Most of such troubles occur on the low-voltage lines, that is, on lines operating between 20,000 and 40,000 volts. What we know as the "factor of safety" of insulators is based on operating voltages and not on lightning voltage. It is thus not really a "factor of safety," as the lightning voltage is the voltage that causes failure. I have mentioned this in former discussions, but as it is a very important point I repeat it here. Lines operating at the voltages mentioned extend out into the same sort of country and are subjected to the same electrical stresses as the higher voltage lines; as the insulators are smaller, greater damage is done. In certain parts of the country there is practically no trouble due to this cause, when the number of insulators in a string exceeds a given number. In an exceedingly severe lightning country this number is seven to eight units. It must be realized that troubles due to this cause can only be eliminated by making the "factor of safety" on the low-voltage lines relatively higher than on the high-voltage lines.

Regarding tests there is one point I should like to make. It is unfortunate that practically all voltages differing from 60 cycles are termed "high frequency" and practically all troubles are attributed to "high frequency." An impulse, or an oscillation, or a wave of steep front, or continuous high frequency, etc., are all given under the same heading. Naturally their effects upon insulators are quite different and there is a great deal of confusion caused. To illustrate: the puncture voltage of an ordinary insulator may be 100 kv. at 60 cycles; at high frequency of 100,000 cycles from an Alexanderson alternator this insulator will break down at 5 kv., due purely to heating; an oscillatory voltage such as has been referred to in one of the discussions this evening will cause puncture at about 120 kv.; a single impulse, depending upon its wave front and duration, will cause failure at anything from 100 kv. to 1000 kv. or more. This readily shows how variable these effects are, yet all are said to be caused by "high frequency." The chief criticism of all such tests so far advocated is that they are absolutely indefinite. "High-frequency oscillation" testing is not a solution of the insulator problem; it is merely a means of testing, sometimes convenient, or sometimes useful as a supplement to the 60-cycle test.*

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* A. I. E. E. TRANS., this volume, p. 1107.

I have recently made some tests using single impulses of a known wave front, length of tail, etc. Impulses with durations measured in microseconds or millionths of seconds have been used. Insulators will stand very high voltages when the duration is short. However, if the voltage is high enough some damage is done to the material. Perhaps a minute crack is formed; the effect is cumulative, and complete puncture results after a sufficient number of impulses has been applied. Such conditions actually occur on transmission lines.

E. D. Eby (by letter): In his paper on insulator depreciation, Mr. Austin points out that mechanical and chemical causes are chiefly responsible for insulator trouble which develops in service. Unequal temperatures in the dielectric, expansion of the cement by weathering or crystallization, and expansion of metal fittings, are mentioned as the chief causes. The paper and the discussion at the meeting dealt altogether with line insulation. I should like to ask whether in his experience Mr. Austin has encountered similar trouble with wall bushings, roof bushings or transformer bushings. It would appear that any of the causes for depreciation given might contribute to trouble with such apparatus as well as with line insulators. On the other hand, the construction of entrance and transformer bushings, particularly of filled types, is usually such that electrical weaknesses may not necessarily follow mechanical damage from cracks, etc. It would be interesting and instructive to learn the experience of manufacturing and operating companies along this line.

Edward J. Cheney (by letter): Insulator reliability becomes increasingly important as transmission distances increase and service requirements become more exacting. Such researches as that of Mr. Austin are, therefore, of the greatest interest and importance.

In one instance a large metropolitan community was absolutely dependent upon a certain transmission line. It was particularly annoying to all concerned to have the insulators on this line begin to fail with disconcerting frequency after they had given fairly good operation for several years and in spite of the fact that the lightning protection had been increased in the meantime. The remedy adopted represented the best which could be done at that time, but is suggestive of brute force rather than science. It consisted in putting on new insulators having a high-potential test double that of the original ones. The results have been good so far, but in the light of the information Mr. Austin has given us, it will now be possible to examine such problems more intelligently and we can be much more confident that the remedy will be permanently effective.

H. H. Sticht (by letter): No doubt the microscope is destined to be an important factor in the study of the insulator, just as it was in the study of iron and steel. Dr. Creighton and

Dr. Steinmetz mentioned the various methods for testing insulators, laying particular stress on the high-frequency and high-voltage tests. There is no doubt but that they are the most reliable tests that can be made in the test room, but how are they to be applied on the transmission line? If the line is one that is built through a level country they might be used. The transformers, with accessories such as a gas engine, and generator, could be mounted on a wagon and driven from tower to tower. But this can be done on very few of our transmission lines. It seems to me that in mountainous or undeveloped country, the megger method is the only one that can be used. I will grant that the method has its limitations, but so have the other methods. Mr. Sothman called attention to the fact that you can make a high-tension test on an insulator, place it on the line, and in a day or so it will break down under operating voltage. Mr. Peek has called our attention to some interesting information regarding the effect of high-tension impulses. Have we any guarantee that a high-potential test, at several times the operating voltage, does not produce a similar result on a small scale? The comparatively low voltage of the megger (1000 to 2000 volts) certainly cannot have any such bad effects. I believe that some of the bad reports about the megger have been caused by engineers trying to use it to detect faulty insulators of the pin type. However, one can readily see that it cannot be used for this class of insulators owing to the fact that a large enough surface cannot be obtained to which to connect the megger.

H. H. Schneider (by letter): In connection with the discussion of Mr. A. O. Austin's paper on insulator depreciation, attention was drawn to the partially defective insulator working in the transmission line. As the elimination of this insulator is of considerable importance, a few words on this subject might be of interest.

Consider any transmission line with its thousands or tens of thousands of insulators. The continual pounding of the elements, external stresses, and line surges, slowly but surely weaken the line insulators. Therefore, at any reasonable time after installation, we have in the line, insulators in every state—from the one as good as the day it was installed to the one on the verge of breaking down. Those in the latter class are of immediate concern, for although capable of withstanding normal potential, they break down when a surge or any abnormal condition arises. Of course, immediate replacing of the destroyed insulator is necessary when the breakdown causes a short circuit. Interruption to service, or the loss of a feeder for an indefinite period, results. Consequently, to make the transmission line as clear as is practically possible, it is incumbent upon us to weed out, systematically, insulators of this description by either periodic test or inspection.

I note that in attempting to weed out these partially defective insulators by means of applying over-potentials to the insulation of the line, it frequently happens that only one or two breakdowns occur upon each application. This requires the locating and the replacing of the defective insulators before the test can be further carried on. Where 15 to 25 bad insulators may be discovered in the course of a test of this nature, a great number of tests is necessary, with the result that the test drags over a considerable period. In order to expedite the test by the rapid replacing of the insulators located by test, men are generally posted along the transmission line right-of-way. Of course, a large number of men is required. Not only is this method of test far from satisfactory when a considerable number of defective insulators is on the line, but the expense connected therewith is also a heavy item. Further, where other live feeders are on the same pole as the feeder under test, the possibility that the arc will flash over to these lines when an insulator breaks down is ever present.

During the course of the discussion several gentlemen referred to the location of partially defective insulators by tests of a different nature. Mr. F. Osgood, I believe, called particular attention to their location through the medium of the ground wire. It would be of interest to have these gentlemen explain somewhat farther in this direction.

A very effective and comparatively inexpensive method of reasonably clearing a line of these insulators is by the following method of inspection. On a rainy night while the line is working under normal potential, the line should be patrolled. Partially defective insulators are readily detected by means of the arcing displayed. Close examination of the insulator can be made by means of high-powered field glasses, but this is only necessary in rare cases where the period between successive arcs is of considerable duration, thereby indicating that the insulator has but a slight defect or that arcing might possibly be due solely to the heavy precipitation. However, it is generally safe to treat this type of insulator as a defective insulator, for the combination of the heat produced by the arc and the rapid cooling of the insulator by the rain is gradually destroying it.

No matter how long the line, if a sufficient number of men is provided, practically all defective insulators can be noted in a single night. The number of times an inspection of this nature should be made depends entirely upon the locality and age of the line. However, three to four times a year is generally ample. Of course, no immediate change of insulators is made while the inspection is in progress, but all defective ones are noted and are replaced the next day.

R. P. Jackson (by letter): It becomes at once apparent that the whole indictment against porcelain is a secondary result of the fact that, for mechanical reasons, porcelain can be used only so as to avoid subjecting it to tension. This is the reason for the use of thin sections backed up by metal in such a way as to keep the porcelain in compression or shear. The ordinary disk suspension insulator is a good example. It is molded into a shape to fit into a head or cap of metal with a metal pin in a re-entrant recess enclosed both by the porcelain and the metal cap.

This necessarily puts the porcelain under severe electrical stress to begin with. Further, unless the cementing is perfect and the coefficients of expansion just right, there are liable to be severe mechanical strains. All efforts to reduce the electrical stress by increasing the porcelain-filled space between the metal parts tends to weaken the mechanical structure of the unit by putting the porcelain under tension or bending moment.

Why not go the whole distance, however, and put the porcelain under direct tension in adequate section and thereby eliminate all trouble from puncture, by surges and lightning?

The chance of there being weak sections or units in a four-piece or five-piece insulator where each piece is only $\frac{5}{8}$ or $\frac{3}{4}$ in. thick is fairly high. On the other hand, what lightning would puncture lengthwise 20 in. of porcelain? Regardless of the so-called factor of safety, such an insulator must flash over rather than puncture.

What is the prospect of making a tougher porcelain, stronger in tension but perhaps of somewhat inferior specific dielectric strength, which would deliver us from turning to the laws of chance to see how much of our equipment is really worse than worthless?

Mr. Austin shows us, indeed, how to make the most of the materials and methods we now have, but at best the laws of chance do not furnish a very satisfactory method of picking out defective material, of which the degree of defectiveness is progressive.

A curious result of the laws Mr. Peek has investigated is the sparking voltage of lightning arrester horn gaps at high voltages in various parts of the country.

Judging from the reports that come back from operating companies, the various horn gap settings sometimes require much greater reduction and enlargement with low and high altitudes respectively than the density law would call for.

There has been a suspicion at times that some other cause, such as the presence of radioactive substances in the vicinity, must be necessary to account for the great horn gap settings required in certain territories. Of course, there may at times be some peculiarity of wave form which accounts for this and causes the discrepancy, but that is rather doubtful.

For example, it is our recollection that on 110,000 volts, settings of horn gaps ranging from four in. in one Western locality near sea level to 15 in. in another in the Rocky Mountains, have been found necessary.

SPECIFICATION AND ANALYTICAL PROCEDURE FOR 30 PER CENT HEVEA RUBBER INSULATING COMPOUND[1]

REPORT OF THE JOINT RUBBER INSULATION COMMITTEE APPOINTED BY A GROUP OF MANUFACTURERS AND USERS OF RUBBER COMPOUNDS,

1911-1914

PREFACE TO REPORT

I. SPECIFICATIONS FOR RUBBER INSULATION

A DEMAND for specifications which will enable purchasers of rubber insulation to secure good material on the basis of competitive bids has existed for many years.

In recent years, there has been no difficulty in securing insulation having the dielectric strength, specific resistance, elasticity and mechanical strength required in practise. Indeed, with the possible exception of dielectric strength, these qualities are usually in excess of actual service requirements. There is another quality, namely permanence, which although equally essential, has not been so easy to obtain.

While the physical properties of rubber insulation are susceptible of positive determination by tests which can be made before acceptance by the purchaser, the permanence of insulation can be ascertained only in practice, often at great loss, inconvenience and even danger. It, should, therefore, be the aim of specifications to overcome this difficulty and by some indirect means, ensure that the manufacturers supply compounds having the required endurance.

This obviously presents a difficult problem, as it requires that some relation be established between permanence and one or more of the properties which are susceptible of test. It has been established by experience that *Hevea* rubber or the rubber of the *Hevea Brasiliensis* tree, when properly cured, is a superior grade which is entirely satisfactory for electrical insulation. *Hevea* rubber may, therefore, be specified with advantage, although certain other rubbers of good quality may be excluded. The rubber has, however, to be further identified as *Hevea* rubber of good quality, the materials associated with it in the compound must be known to be non-deleterious and the compound itself must be well prepared, applied and vulcanized.

Two types of specifications have been devised to compass these restrictions. The first type of specification proceeds on the assumption that certain physical characteristics are developed to an unusual degree by the use of *Hevea* rubber, especially the grade known as fine *Para*. Among the qualities affected by the grade of rubber, and alleged to be useful indications of the presence of *Para* rubber, are the tensile strength, elasticity and specific resistance. Accordingly some specifications have been issued in which one or more of these qualities is specified in an exaggerated degree. Experience has shown that such specifications are ineffective, as the specified physical quality can be obtained either by manipulation of poor compounds or at the expense of permanence in compounds made originally of good materials. In consequence of this, specifications based exclusively on physical tests have fallen into disrepute, but such tests now serve in modified form as adjuncts to other types of specifications.

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[1] This report has been referred to the Standards Committee of the A. I. E. E. for consideration, and was printed in the PROCEEDINGS at the request of that Committee.

The second type of specification to be considered is that in which a more or less rigid formula for the compound is specified and compliance with it exacted either by inspection during manufacture, or by chemical analysis supplemented by other tests of the finished product. Inspection which will really ensure compliance with such specifications is usually impracticable. Reliance must, therefore, be placed principally upon chemical analysis. Three difficulties at once arise. In the first place chemical analysis cannot *directly* ascertain the quality or quantity of the rubber which has been used in the manufacture of a compound; it can only determine these by the *indirect* method of measuring certain of its characteristic constituents. It is, therefore, necessary to present in the specification, a relation between the desired formula and the chemical findings.

The second difficulty is that in the past, chemists have employed diverse methods of analysis which give inconsistent results. It is, therefore, necessary to establish a satisfactory and standard procedure for analysis. The method of analysis must not only yield the information desired, but it must also be practical and capable of yielding uniform results when applied to the same compound by different chemists. In order to secure this uniformity, it is important to describe the methods of analysis in detail.

The third difficulty has been the non-uniform interpretation of analytical results.

The specification hereinafter presented is of the second or chemical type, in which an endeavor has been made to meet the three objections hitherto urged against such specifications. It contains a table showing the range of analytical results that should be obtained from a good compound containing 30 per cent of high class *Hevea* rubber, and is supplemented by a detailed analytical procedure. The specification is not complete as given, it being necessary to add appropriate electrical and mechanical test requirements.

The specification presented in this report should always be used in conjunction with the analytical procedure. The latter will, however, serve for the analysis of any compounds of the 30 per cent *Para* type with mineral fillers, provided the interpretation is made to correspond.

II. Standardization of Specifications

The necessity of purchasing insulated wire under conditions of competitive bidding led the various departments of the government, the railroads and other large consumers, to issue specifications for rubber insulation. These specifications were based upon the individual experience or theories of a number of engineers, aided by suggestions from some of the manufacturers. For several years no attempt was made to standardize these specifications, and much trouble was given to the manufacturers by the diversity of requirements contained in them. In 1906, the Rubber Covered Wire Engineers' Association, consisting of representatives of the leading manufacturers, prepared a specification which was offered as a standard. This was followed in 1911 by the revised specifications of the National Board of Fire Underwriters, which, however, call for a comparatively low grade of compound. The former specification, although the best that could be agreed upon at that date, was so defective as to afford little or no protection to consumers. The latter occupies a field by itself, and make no pretension to specifying the highest quality of compound. Consumers desiring compounds of great permanence, therefore, continued to use their own specifications, altering them from time to time, in accordance with the best information available, with a growing tendency to rely upon chemical rather than physical tests. Some difficulty was experienced in enforcing these specifications owing to the inability of chemists to make concordant analyses of rubber compounds. This matter reached an acute stage in 1911, when Mr. E. B. Katte, Chief Engineer of Electric Traction of the N.Y.C. & H.R.R.R. Co., invited a number of manufacturers and consumers to a conference in order to discuss the possibility of standardizing specifications and analytical methods for rubber insulation. This conference was held at New York on the seventh of December, 1911, Col. Samuel Reber of the U.S. Signal Corps presiding.

After a full discussion of the subject, a committee was appointed to devise a specification and an analytical procedure for rubber insulation, the committee to report at a future conference.

This committee, which was originally known as the Railroads Rubber Committee and later as the Joint Rubber Insulation Committee, worked at the problem assigned to it for two years and presented a report to a second conference which was held at New York on October 15th, 1913, Col. S. Reber again presiding. The report was unanimously accepted by the Conference and the Committee authorized to continue in existence for another year for the purpose of making any revisions that might appear necessary in its report, as the result of a year of experience with it.

The membership of the general conferences at which the committee was appointed and to which its report was submitted, consists of representatives of the following interests:

U. S. Signal Corps,
U. S. Bureau of Standards,
American Chemical Society,
Lederle Laboratories,
New York Central Lines,
Pennsylvania R. R.,
General Electric Co.,
Hazard Manufacturing Co.,
Simplex Wire & Cable Co.,
Standard Underground Cable Co.

The organizations represented in the committee have been unstinting in devoting their unrivalled resources to this work, which could not have been carried out by private enterprise.

While the acceptance of the report does not bind any of these interests to the official adoption of the specification and analytical procedure, most of the members were of the opinion that they would be adopted in due course.

The Association of Railway Electrical Engineers has adopted the specification in its standard wire specifications, and the Power Distribution Committee of the American Electric Railway Association has recommended its adoption by the latter association.

It is hoped by the Committee that other societies and users of rubber insulation will follow this lead and help to abolish the existing multiplicity of specifications and methods of analysis.

The Committee wishes to emphasize the preliminary character of the report and urges everyone interested in the subject to send to the Secretary any suggestions or criticisms which may be of value, so that such statements may receive consideration before the publication of the report in its final form.

The Committee also desires to express its thanks to the many gentlemen not members of this committee, who have participated in the work, especially to Messrs. D. A. Cutler, F. Dannerth, F. S. Deemer, F. A. Hull, M. M. Kahn, G. H. Savage and D. Whipple.

III. Rubber

Those who are not familiar with the nature and sources of rubber may find some difficulty in understanding the report. The following brief outline of these subjects is therefore given, containing the best information that could be gathered.

Rubber is derived from certain tropical trees, creepers and shrubs found chiefly in South and Central America, Africa, and Southern Asia. When certain species of these plants are tapped, a thick milky-looking fluid or latex exudes from them. This latex is composed of very minute oil-like colorless refractive globules. Besides these globules, called caoutchouc or rubber-gum proper, which have a chemical composition represented by the formula $(C_{10}H_{16})_n$, the serum contains resins, protein and other compounds. Rubber is the coagulated latex, consisting of rubber-gum admixed with these impurities.

Rubber is furnished in America principally by the *Hevea*, *Micandra*, *Manihot*, *Castilloa* and *Hancornia* plants, usually in the wild state.

In Africa the principal plants are the *Landolphia*, *Clitandra* and *Kickxia*, also wild.

In Asia, there are the *Ficus* in the wild state and the *Hevea* in the state of cultivation.

In the Amazon valley, there are numerous species of *Heveas*, of which the most important is the *Hevea Brasiliensis*. This tree furnishes the most highly esteemed quality of rubber.

The *Heveas* in the Brazilian forests are cylindrical trees of an ashy color, from 20 to 30 meters high, and attaining a diameter of from 0.80 to 1.20 meters.

The usual process of tapping these trees is as follows: Incisions are made at about 3 to 3½ meters from the ground, by means of a long-handled hatchet. The object of this operation is to make the latex ascend from the roots, in an effort to repair the incisions. The milk that oozes out is mixed with bark and other impurities and is utilized to make an inferior grade of rubber known as sernamby. Two days afterwards, incisions are made 2 meters from the ground and tapping cups fastened at the lower part of them. The latex collected in these cups is said to be collected "prime" and furnishes the best rubber. On the following day, the process is repeated by making incisions about 7 cm. below the first, this being continued on successive days until the ground is reached.

The rubber is coagulated from the latex by smoking. This is accomplished by putting the latex on a spatula or flat stick, and holding it over a fire made from wood or Urucuri nuts, the smoke of which is rich in acetic acid and creosote or similar oily substances. The latex is thus dried in successive layers until a ball or biscuit weighing from 20 to 60 kg. is obtained. The smoke acts as a coagulant, evaporates the water and at the same time kills bacteria, which would cause decomposition. Rubber prepared in this way is known as "fine *Para*", but when the curds or semi-solidified latex deposited in the latex basin are incorporated with it, the quality is lowered and the product is known as "entrefine" or "medium fine". If these natural curds are collected separately, they are known as "coarse Para" or "sernamby", a name which, as mentioned above, is also applied to rubber coagulated on the bark of the tree. *Up-river Para* rubber is *fine Para* collected from the *Hevea Brasiliensis* trees in the headwaters of the Amazon and its tributaries.

The wild *Hevea* rubber of Brazil is shipped in biscuits which contain from 15 to 20 per cent of impurities, which can be removed by rolling and washing with water preparatory to use in manufacture. These impurities are absent from plantation rubbers, a circumstance which must be considered when the prices of wild and plantation rubber are compared.

Several kinds of rubber trees are raised on plantations, but the most important kind is the *Hevea Brasiliensis*. Just as the rubber of this tree in the wild state varies slightly in composition according to its habitat on the upper or lower reaches of the Amazon river, so in the cultivated state, a similar variation exists, but to a greater degree. The principal source of plantation rubber is Southern Asia.

The latex of plantation rubber is collected in much the same way as in the case of wild rubber, but coagulation is usually effected by the addition of chemicals. As such coagulation does not usually have the preservative effects of smoking, the better grades of plantation rubber are "cured" by exposure to antiseptic smoke.

The principal forms in which plantation rubber is prepared, are crepe and sheet, either of which may or may not be smoked.

In the preparation of crepe, the strained latex is poured into pails and a small quantity of acetic acid is added. This curdles the latex, the curds rising in the serum. The resultant curd is passed between steel rollers under a stream of water. From this process, the rubber emerges in long, thin, corrugated strips, having the appearance of crepe. The process is completed by drying.

For preparing sheet or biscuit, the latex is set in shallow pans, the acid added and the clot allowed to stand until it sets quite firm. The water is then squeezed out and drying completed in hot rooms. The curds which do not rise with the main clot are made into an inferior grade of rubber.

Curing is effected by hanging the rubber in an atmosphere impregnated with creosoted smoke, thus antiseptizing the rubber. It should be observed that coagulation with acetic acid and curing with creosote chemically simulates the Brazilian process of smoking with the *Urucuri* nut.

Both wild and plantation rubber are used in the manufacture of insulating compound. It is claimed that some difficulty is experienced in obtaining a high tensile strength with some plantation rubbers, and their lasting qualities have not been established as well as those of wild Brazilian rubber. It is, therefore, desirable, where the greatest durability is to be insured, that the grade of rubber should be *fine Para* or a plantation rubber of good grade which is practically indistinguishable from it by chemical tests, when compounded.

Most high grade rubber compounds for insulating wire are prepared by mixing rubber gum with sulphur and mineral or organic fillers, such as paraffine wax, ozokerite, ceresine, zinc oxide, talc, whiting, litharge, barium sulphate, and basic lead sulphate.

These ingredients are thoroughly mixed on heavy steel rolls, after which the plastic compound is either pressed on to the wire through dies or applied in the form of a longitudinal strip which is pressed into tubular form around the wire.

The covered wire is then placed in a chamber or vulcanizer containing either steam under pressure, or heated air. The duration of this heat treatment varies from less than one hour to several hours, depending upon operating conditions and the temperature, which is usually from 120 to 150 deg. cent. Under these conditions the sulphur combines with the rubber to form vulcanized rubber. This process of compounding and vulcanizing changes the character of the rubber so that its strength, insulating qualities and durability are enhanced.

W. A. Del Mar,
P. Poetschke,
E. L. Willson.
Sub-committee on publication of report.

PRELIMINARY REPORT OF COMMITTEE

Part I —General Report.
" II —Analytical Procedure.
" III—Explanation of Procedure.
" IV —Specification.
" V —Explanation of Specification.

PART I—GENERAL REPORT

1. At the Conference of December 7th, 1911, it was resolved that a Committee be appointed to develop a means of specifying and analyzing rubber insulation, the Committee to report its findings at a future conference.

2. The Chairman of the Conference, assisted by other members, appointed the following to serve upon this Committee:

Mr. C. R. Boggs, Simplex Wire & Cable Co.,
Mr. W. S. Clark, General Electric Company,
Mr. W. A. Del Mar, N.Y.C. & H.R.R.R.Co.,
Mr. W. B. Geiser, " " " "
Mr. J. P. Millwood, Consulting Chemist,
Mr. P. Poetschke, Lederle Laboratories,
Mr. H. B. Rodman, Pennsylvania R. R. Co.

Later, at the request of the Committee and by unanimous consent of the members of the original Conference, the following were added:

Mr. J. B. Tuttle, U.S. Bureau of Standards,
Mr. E. L. Willson, Hazard Manufacturing Company.

The Committee thus constituted is composed of three railroad men, three independent chemists, and three representatives of the manufacturers. Of the nine members, seven are chemists and two are engineers.

3. The Committee immediately upon its formation decided to confine itself to the development of a specification and an analytical procedure for compounds of the 30 per cent *Para* type. In accordance with this policy it considered the available analytical procedures and developed several which formed the basis of further study. Samples of different rubber compounds were analyzed by these tentative methods. The results were unsatisfactory and the discrepancies were investigated. Subcommittees were formed to do much of this work. Twelve regular committee meetings, besides numerous sub-committee meetings, were held; thirteen different compounds were distributed to be analyzed by the entire committee, and many more compounds were experimented upon by the sub-committees and individual members.

4. The outcome of this work has been a gradual elimination of errors and the development of a procedure which, with experience, will give uniform and consistent results.

5. The Committee feels that the procedure which it has developed is not perfect and believes that it should be put into use for a year before being offered as final. With this in view the Committee hereby presents to the Conference, a preliminary procedure and requests the permission of the Conference to publish it and obtain the results of experience with it during the ensuing year. The Committee proposes to avail itself of the experience gained in this year and to incorporate whatever improvements it may decide upon in a final report.

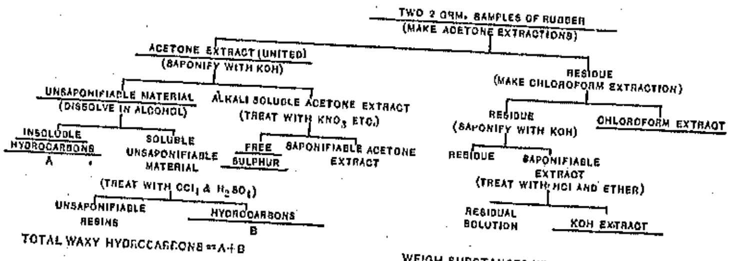
6. The Committee has also made a study of specifications for rubber insulating compound. It presents herewith a chemical specification for a compound containing 30 per cent of *Hevea* rubber with mineral fillers and requests that this specification, like the analytical procedure, be considered as tentative.

7. There may still exist the possibility of making compounds which will conform to the specification when analyzed by the procedure, but which are not compounded as desired. The Committee believes, however, that the probability of such compounds being supplied is very small indeed. After more experience with the procedure it may be possible to narrow the limits prescribed in the specification.

Part II— Procedure for the Analysis of Rubber Compound

Object of the Analysis

1. The object of this procedure of analysis is to determine whether rubber compounds comply chemically with the accompanying specification which is intended to secure compounds containing 30 per cent of the best *Hevea* rubber, and mineral fillers.



WEIGH SUBSTANCES WITH NAMES UNDERLINED
OTHER SUBSTANCES BY DIFFERENCE

Diagram A.—Outline of Method of Rubber Analysis Exclusive of Fillers and Sulphur Determinations

Outline of Procedure

2. The general procedure is shown by the accompanying diagram A, which gives an outline of the separations to be affected by acetone and chloroform extractions, and saponification with alcoholic potash.

General

3. Make the analysis upon the insulation after vulcanization and, whenever possible, before the saturation of the braid. Wipe the insulation thoroughly with a damp cloth to remove any adhering material, but do not remove waxy hydrocarbons from the surface.

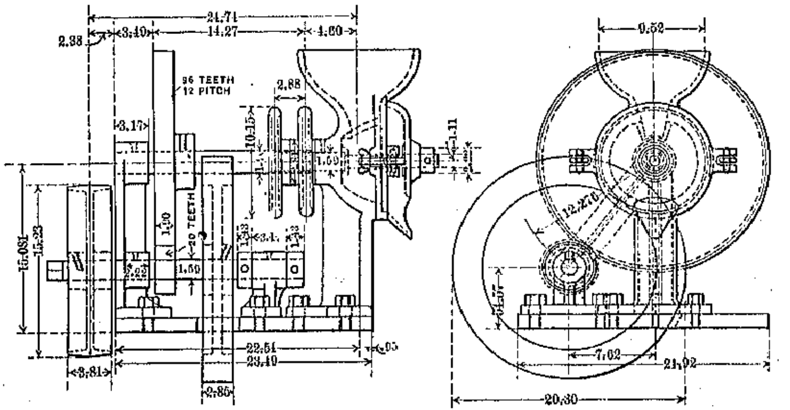
4. If, however, a saturated braided sample must be used, remove the braid and sandpaper the insulation to a depth of at least 5/1000 of an inch and wipe with a damp cloth. In such cases report the condition of the sample.

5. Perform all determinations in duplicate and take the average value arbitrarily as the true value. Duplicate determinations must check within the limits specified.

6. Make blanks on all determinations and deduct the results accordingly.

Sample

7. Remove the insulation entirely from sufficient wire to give a sample weighing about 25 grams. Cut this into small strips and grind slowly in either a No. O Enterprise coffee mill or a mill such as shown by the accompanying diagram B. Adjust the grinder so that not more than 20 per cent will pass through a 40-mesh sieve. Sift all the material through a 20-mesh sieve, regrinding what is retained on the sieve until the entire sample has passed through. The wires of the sieves shall be evenly spaced in both directions and shall be of 0.016 and 0.010 inches diameter in the 20 and 40 mesh sieves respectively. Remove with a strong magnet any metal that may have come from the grinder and thoroughly mix the sample.



GRINDING PLATES OF THE NO.0
ENTERPRISE COFFEE MILL TO BE USED

DIAGRAM B.—RUBBER GRINDER
(All dimensions in centimeters)

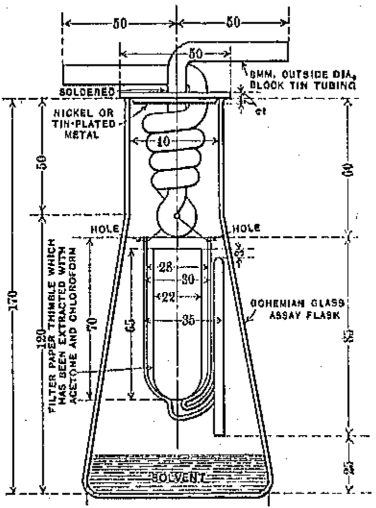

50
50
50
SOLDERED
8MM. OUTSIDE DIA, BLOCK TIN TUBING
NICKEL OR TIN-PLATED METAL
40
50
60
HOLE
HOLE
28
30
22
35
BOHEMIAN GLASS ASSAY FLASK
FILTER PAPER THIMBLE WHICH HAS BEEN EXTRACTED WITH ACETONE AND CHLOROFORM
170
120
70
65
85
25
SOLVENT
80

DIAGRAM C.—RUBBER ANALYSIS
EXTRACTION APPARATUS
(All dimensions in millimeters)

Extraction Apparatus

8. The extraction apparatus shall conform with the accompanying diagram C. It shall be heated so that the period of filling an empty syphon cup with acetone and completely emptying it, will be between 2½ and 3½ minutes.

Preparation of Reagents

9. Acetone shall be freshly distilled over anhydrous K_2CO_3 using the fraction 56-57 deg. cent.

10. Alcoholic KOH solution shall be of normal strength and shall be made freshly by dissolving the proper amount of KOH (purified by alcohol), in 95 per cent alcohol which has previously been distilled over KOH. The solution shall be allowed to stand for 24 hours and only the clear liquid used.

11. Ether shall be washed with three successive portions of distilled water and distilled, using the fraction 34-36 deg. cent.

12. Chloroform shall be pure and freshly distilled.

13. Carbon tetrachloride shall be pure and freshly distilled.

14. Reagents not otherwise specified shall be c.p.

Acetone Extraction

15. Extract continuously with 60 cu.cm. acetone for eight hours, two 2-g. samples that have been prepared within 24 hours. Unite the extracts in a weighed flask, using hot chloroform to rinse the flasks. Distill off the reagents and dry the flask and contents for four hours at 95-100 deg.cent. Desiccate until cool and weigh. Continue to dry for two-hour periods until constant weight is obtained. In drying, place the flask on its side but at a sufficient angle from the horizontal so that the extract does not appreciably run down the side of the flask.

Unsaponifiable Material

16. Add to the acetone extract 50 cu. cm. alcoholic KOH solution, boil under a reflux condenser for two hours, and evaporte to dryness, removing all alcohol. Add 10 cu.cm. water and 20 cu.cm. ether; heat until the wax etc. are in solution, cool, transfer to a separatory funnel, wash out the flask with warm water and then cool, finally with two 20 cu.cm portions of ether. The water volume should be 100 cu.cm. and the ether at least 40 cu.cm. Shake vigorously for two minutes, and allow the solu- tions to separate thoroughly. Draw off the aqueous solution into a second funnel, leaving in the first funnel the etherial solution and any floc- culent material that may be present. Again rinse the flask with 20 cu.cm. ether and add it to the aqueous solution; shake vigorously for two min- utes, and when separated draw off the aqueous solution and unite in the first funnel the etherial solutions and any flocculent material. Repeat, shaking with 20 cu.cm. portions of ether until the extraction is complete, using at least 120 cu.cm. ether. Wash the flask and the funnel, from which the etherial solution has been taken, with water, until they are free from alkali, subsequently using this wash water to wash the etherial solution. Continue washing with water until it has been washed twice after it shows no alkaline reaction. Retain with the etherial solution any flocculent material. Filter the etherial solution from the flocculent material, through a small pellet of extracted cotton, into a weighed flask, washing first with ether and subsequently with hot chloroform, using this to rinse the original flask and both separatory funnels. Evaporate the solvents and dry the extract to constant weight at 95-100 deg.cent; desiccate until cool and weigh.

Hydrocarbons A

17. Add 50 cu.cm. absolute alcohol to the unsaponifiable material and warm until solution is as complete as possible. Cool the solution to −4 or −5 deg.cent. and maintain at this temperature for one hour by pack-

ing the flask in a mixture of ice and salt. Filter out the waxy hydrocarbons, using a funnel packed with ice and salt, and apply suction if necessary. Wash the flask and filter with about 25 cu.cm. of 95 per cent alcohol, which has been previously cooled in the same temperature. Catch the filtrate in a flask which is afterwards cooled to −4 or −5 deg.cent. to make sure that all possible waxy hydrocarbons have been removed, and refilter if necessary. Dissolve the residue on the filter paper with hot chloroform, into the original flask. Evaporate the chloroform and dry the flask to constant weight at 95-100 deg.cent.; cool in a desiccator and weigh.

Hydrocarbons B

18. Evaporate the alcohol from the flask containing the alcohol soluble unsaponifiable material add 25 cu.cm. carbon tetrachloride and transfer to a separatory funnel. Shake with conc. H_2SO_4, drain off the discolored acid and repeat with fresh portions of acid until there is no longer any discoloration. After drawing off all the acid, wash the carbon tetrachloride solution with repeated portions of water until all traces of acid are removed. Transfer the carbon tetrachloride solution to a weighed flask; evaporate off the solvent and dry the flask to constant weight at 95-100 deg.cent. Cool in a desiccator and weigh.

Free Sulphur

19. Add two grams KNO_3 to the aqueous solution and washings from the etherial separation of the unsaponified material. Evaporate to dryness in a silver or nickel dish and heat to quiet fusion, avoiding contamination with sulphur fumes. Transfer with water to an evaporating dish, acidify with HCl, evaporate to dryness, and dehydrate silica. Add 2 cu.cm. conc. HCl, take up in water, filter and wash, making a volume of 200 cu.cm. Heat to boiling and add slowly a slight excess of hot 10 per cent $BaCl_2$ solution. Allow to stand over night, filter, wash, ignite, weigh the $BaSO_4$ and calculate to sulphur.

Definition of Terms Describing Compounds of Acetone Extract

20. The difference between the Acetone Extract and the Free Sulphur shall be called the Organic Extract.

21. The difference between the Organic Extract, and the Unsaponifiable Material shall be called the *Saponifiable Acetone Extract.*

22. The sum of the Hydrocarbons A and B shall be called the total *Waxy Hydrocarbons.*

23. The difference between the Unsaponifiable Material and the Waxy Hydrocarbons shall be called *Unsaponifiable Resins.*

Chloroform Extraction

24. Extract continuously the residue from one of the acetone extractions, (without necessarily removing the acetone that may be on it), for four hours with 60 cu.cm. chloroform, using a weighed flask. Distill off the solvent and dry the flask and contents for two hours at 95-100 deg. cent. Desiccate until cool and weigh. Continue to dry for one hour periods until constant weight is obtained. In drying, place the flask on its side but at a sufficient angle from the horizontal so that the extract does not appreciably run down the side of the flask. (If it is needful to wait after the acetone extraction, before starting the chloroform extraction, the sample must be kept in a vacuum of at least 50 mm. of mercury.)

Alcoholic Potash Extraction

25. Dry the residue from the chloroform extraction at 50-60 deg.cent., put into a 200-cu.cm. Erlenmeyer flask with 50 cu.cm. alcoholic KOH solution and boil for four hours under a reflux condenser. Filter the solution into a beaker and wash twice, using each time 25 cu.cm. hot absolute alcohol and then wash thoroughly with hot water. Evaporate the solution to approximate dryness, take up in warm water and transfer to a separatory funnel. Acidify with 15 cu.cm. 5 normal HCl, using this to rinse the beaker. Add sufficient water to make the bulk of the solution 100 cu.cm. When cool add 40 cu.cm. ether, using it to rinse the beaker in 20-cu.cm. portions. Shake the aqueous and etherial solutions thoroughly. After complete separation, draw off the aqueous solution and treat in another separatory funnel, with a fresh 20-cu.cm. portion of ether. Continue to shake the aqueous solution with fresh portions of ether until a colorless portion has been obtained, then shake out twice more. Unite the etherial solutions and wash with successive additions of water, continuing twice after the water shows no acid reaction. Filter through a plug of extracted cotton into a tared flask, wash the filter and funnel with ether, evaporate the ether without boiling and dry the residue to constant weight at 95-100 deg.cent. Cool in a desiccator and weigh.

Fillers

26. Extract a 1-g. sample with acetone for five hours. Transfer the residue to a tall lipped 200-cu. cm. beaker, add 40 cu.cm. terebene and 20 cu.cm. xylol and heat on an oil bath at 105-110 deg.cent. for about 20 hours, or until the bulk of the fillers settle promptly after stirring. Occasional stirring will aid the solution. Allow the beaker to stand until the fillers and undissolved residue have settled thoroughly and decant the supernatant solution into a beaker. Add to the undisturbed residue 30 cu.cm. terebene; heat for several hours, allow to settle, decant, unite the decanted solutions and repeat this treatment as long as there is any indication of rubber being present. Continue to heat the decanted solutions during the further treatment of the undissolved residue and filter them through a tared filter paper. This filter paper must be of close texture and shall have been washed with terebene, alcohol and acetone. The tare filter shall be treated with the same solvents and dried in the same manner throughout the analysis as the filter containing the residue. Weigh all filter papers in weighing bottles of sufficient size to take them without folding. Refilter if mineral matter runs through. Wash the beaker that contained the decanted solutions and the filter paper, with benzol, using a second beaker to catch the filtrate. Add benzol to the beaker containing the residue, heat and after settling decant, repeating this treatment with benzol until it is thoroughly washed. Filter and wash well with benzol. Wash in the same manner both beakers with hot alcohol and then transfer the residues to the filter paper, using hot alcohol and an acetone extracted policeman. Wash finally with acetone. Dry in air at 95-100 deg.cent. and weigh. Again wash the filter paper and contents with benzol and alcohol, dry, weigh and repeat this treatment until constant weight is obtained. Evaporate all the filtrates and washings, transfer to a porcelain dish, burn off and weigh. Add this amount to the fillers found above. If this ash is greater than 1 per cent, the entire

determination shall be repeated. Subtract 0.5 per cent as anarbitrary value for the amount of organic matter from the rubber retained with the fillers.

Sulphur in Fillers

27. Transfer the fillers from the filter paper into an iron crucible; burn the filter paper and add the ash to the crucible. Add the Total Sulphur flux and proceed with the determination of sulphur as in Section 28, Total Sulphur. Subtract the percentage of sulphur found from the percentage of fillers to determine the percentage of fillers free from sulphur.

Total Sulphur

28. Mix a 0.5-g. sample with 4 g. Na_2O_2 and 6 g. K_2CO_3 in a dry 15-cu.cm. iron crucible. Cover and heat gradually until the mixture fuses, proceeding cautiously, as rapid heating will cause an explosion, and then bring to quiet fusion for 15 to 20 min. Apply the heat so as to avoid contamination with sulphur fumes. Rotate the crucible while the melt solidifies. When cool, put crucible and cover into a casserole containing 200 cu.cm. of water; add 5-10 cu.cm. bromine water and boil until the melt is dissolved. Allow the precipitate to settle, decant the liquid through a thick filter and wash the residue with hot water. Acidify the filtrate with HCl, evaporate to dryness and dehydrate silica; add two cu. cm. conc. HCl., take up in water, filter and wash, making the total volume about 400 cu.cm. Heat to boiling and add slowly a slight excess of hot 10 per cent $BaCl_2$ solution. Allow to stand over night, filter, wash, ignite, weigh the $BaSO_4$ and calculate to sulphur.

Specific Gravity

29. The specific gravity shall be the ratio of the weight of a given volume of the rubber, to the weight of an equal volume of water, both at 20 deg.cent. Cut strips of the largest applicable size from the conductor and use about 5 g. for the sample. Determine the specific gravity in the usual manner by means of a specific gravity bottle. Care must be taken that no air bubbles adhere to the sample.

Checks

30. Specific gravity determinations shall check within 0.01. The other duplicate determinations shall check within the following limits expressed as percentages of the original sample.

Determination	Check
Acetone Extract	0.10
Saponifiable Acetone Extract	0.10
Unsaponifiable Resins	0.10
Waxy Hydrocarbons	0.10
Free Sulphur	0.05
Chloroform Extract	0.10
Alcoholic Potash Extract	0.10
Fillers, free from sulphur	0.50
Total Sulphur	0.10

Interpretation

31. The *Rubber* shall be considered to be the difference between 100 and the sum of the Waxy Hydrocarbons, Total Sulphur and the Fillers (free from sulphur), expressed as percentages. If the Chloroform Extract is over 3.0 per cent of the rubber so calculated, subtract the excess from the Rubber. If the KOH extract is over 1.8 per cent of the Rubber, as first calculated, subtract this excess also from the Rubber.

Carbon and Red Lead

32. Heat about one g. of the sample with 30 cu.cm. conc. HNO_3 and 15 cu.cm. water. A black insoluble residue indicates the presence of carbon.

When the rubber is dissolved, in the fillers determination, the absence of any red particles indicates the absence of red lead. If red particles are present, dissolve another sample by the same method as the fillers (Section 26), filter the solution into a Gooch crucible and wash thoroughly. Remove the felt and residue to a distilling flask, add HCl, and distill over the chlorine liberated by the lead peroxide, absorbing the gas in a solution of KI and starch. Not more than 0.1 cu.cm. $\frac{N}{10}$ thiosulphate shall be required to titrate the iodine liberated.

Statement of Results

33. The results of the analysis shall be stated in the following form:

Per cent

- Acetone extract..
  - Saponifiable acetone extract...............................
  - Unsaponifiable resins....................................
  - Waxy Hydrocarbons.....................................
  - Free sulphur...
- Chloroform extract..
- Alcoholic Potash extract..................................
- Fillers free from sulphur..................................
- Total sulphur...
- Rubber...
- Color of acetone extract (60 cu.cm. vol.) ....
- Fluorescence in acetone extract solution (present or absent).......
- Hydrocarbons A (consistency and color).......................
- Hydrocarbons B (solid or liquid).............................
- Color of chloroform extract (60 cu.cm. vol.)....................
- Carbon (present or absent).................................
- Red Lead (present or absent)...............................
- Specific Gravity...

Part III—Explanation of Procedure

General

1. The Committee felt the more acceptable solution of its problem of drawing up a procedure which would give the percentage of rubber present in a compound with a reasonable degree of accuracy, to be the perfection and amplification of the difference method rather than the development of a direct method, which if equally correct, might not inspire confidence because of the comparative novelty of its application to this purpose.

2. The most feasible means of limiting the kind of rubber, was considered to be the determination of the saponifiable and unsaponifiable resins. These are fairly constant characteristics of the resins of *Hevea* rubber, and of compounds made from the same. Other methods, such as the determination of the saponification number and the optical activity of the resins, were thought to be unpractical.

3. The method as developed is applicable to the analysis of any pure rubber compound containing only mineral matter with or without ceresine or paraffine wax, regardless of the kind or amount of rubber, and can

be used in conjunction with other specifications provided the limits are changed to correspond with the amount and kind of rubber desired, and due consideration is given to interfering mineral matter. When applied to a compound without ceresine or paraffine wax the unsaponifiable acetone extract is the unsaponifiable resins.

4. The method has been definitely described, to make it certain that experienced chemists may obtain concordant results. The interpretation has been rigidly defined, obviating any ambiguity as to the meaning that will be assumed, even though this sometimes appears to be arbitrary.

Sample

5. In order to obtain uniform results, the Committee has established by experiment that a definite method of sampling has to be adopted and that for all extractions the sample must be reduced in a prescribed manner to at least an approximately similar degree of fineness. For this reason the procedure specifies a definite type of grinder obtainable in two forms, and also specifies definite sieves.

Extraction Apparatus

6. The Committee has proved that the extraction apparatus used by different chemists must be of exactly the same form and the same size. It was also proven that small samples in the apparatus give the maximum results and that the rate of extraction is dependent upon the amount of solvent and its temperature as it passes through the sample. The apparatus finally adopted combines the advantages of several forms that were studied and together with simplicity of operation and adjustment to uniform conditions, gives practically complete extraction when used as specified. A number of other variations that might have a possible effect upon the amount of extract, were tried but found to be inappreciable.

Acetone Extraction

7. The extraction is made within 24 hours of the preparation of the sample, so obviating any appreciable oxidation. Two samples are extracted and united, so that a larger amount of extract may be obtained for the subsequent separations, and the extraction apparatus kept within a convenient size. Hot chloroform is used to facilitate the complete transference of the extract. The flasks are placed on their sides when drying, to hasten the emission of the solvent and thus reduce chance of volatilizing, through longer heating, some of the more volatile constituents of the extract. Drying in vacuo at room temperature, does not remove all the moisture if paraffine is present and such drying with heat or at 100 deg. cent. in an inert gas, presents no practical advantage over the method given.

Separation of the Acetone Extract

8. The method given was devloped so that all the desired constituents could be determined on one sample.

9. Emphasis is laid on thorough extraction of the unsaponifiable material and the retention of the flocculent material with the etherial solution. This latter material is not soluble in either ether or water, but it was proven that if such as was chloroform-soluble was included in the unsaponifiable material, the subsequent determination of the hydrocarbons would be more exact. A portion of this flocculent material is insoluble in chloroform.

10. The hydrocarbons are determined in two places, making an approximate separation between the solid and the liquid ones, if both are present. The first hydrocarbons (A) are those insoluble in the solvent at a low temperature. The presence of unsaponifiable resins in the solution prevents the more complete freezing out of the hydrocarbons, but the remainder is obtained after treatment of the resins with sulphuric acid. In this way, chance of loss through the action of the acid has been largely eliminated.

11. The method for free sulphur gives all the sulphur in the acetone extract with the exception of negligible amounts which may be in the unsaponifiable material. It was proven that the results agree with determinations made directly on other acetone extracts.

12. The saponifiable and unsaponifiable resins are obtained by difference.

Chloroform Extraction

13. The chloroform extraction should be made at once after the acetone extraction, or the sample put in a vacuum, so as to avoid the danger of an abnormally high extract. When the extract is dried as specified, constant weight is obtained before any appreciable oxidation occurs. If bituminous substances are present, that portion which has not been extracted by the acetone, will be largely soluble in chloroform and can be readily distinguished by its color. The amount of extract is also affected by the presence of uncured rubber and rubber of low degree of polymerization. A properly cured *Hevea* compound will always give a little extract with chloroform, which varies somewhat with the method and conditions of cure.

Alcoholic Potash Extraction

14. The alcoholic potash extraction is the usual saponification process for obtaining the fatty acids of rubber substitutes. The total amount of such substitutes is not obtained, but if any appreciable amount is present, the value will exceed that of the limit allowed. When no substitutes are present, this determination always yields a small amount of extract from *Hevea* rubber.

Fillers

15. Since the rubber is determined by difference, it is necessary to determine the amount of fillers. Ashing the compound gives accurate results provided no volatile or decomposable fillers are included. This, however, cannot be assumed to be the case. The determination of fillers by using solvents to dissolve the rubber, has always presented a difficult problem and it is only after a great many experiments that the Committee can report a reasonably satisfactory method.

16. Many kinds and probably every class of rubber solvents were tried, with the result that some did not completely dissolve the rubber at low temperatures and ordinary atmospheric pressure; others appeared to dissolve the rubber, but formed a colloidal solution holding some of the fillers which could neither be filtered nor centrifuged clear of mineral matter, and the ones that did not present these difficulties consumed much time.

17. Terebene was found to be the solvent which would most completely dissolve the rubber and after continued heating would completely destroy the rubber in solution as such, and so break up the colloidal solution. Filtering out the mineral matter is then a comparatively simple

process. The treatment with terebene must be performed in the presence of air to break up the colloidal solution. A disadvantage of using terebene is the length of time required to obtain satisfactory solution. The speed is greatly hastened if at first xylol is used with the terebene. After decanting this solution, terebene is used alone. The rapidity of the action is also hastened by increasing the temperature. That specified gives reasonable speed without serious danger of carbonizing the rubber or of losing any of the fillers by decomposition.

18. It was proven that there is organic matter derived from the rubber, which is insoluble in the solvents and remains with the fillers. Without taking this into account, the fillers will appear high, and the rubber by difference, low. As this organic matter was proven to be largely proteid matter, and this was originally a part of the rubber, an allowance is made for it. This is the amount generally retained when the method is carried out as specified. It is possible, by centrifuging, to throw out of the solution a great deal more than this, and it is also possible to determine the approximate amount retained in each case, but the slight increase in accuracy does not justify the extra determination.

19. Most of the details of this procedure are self-evident, but it is probably worthy of note that the benzol solutions are filtered into a separate beaker, as otherwise the benzol is apt to precipitate, from the terebene solution, organic matter which may be mistaken for mineral matter or conceal mineral matter passing through the filter. The filtrates are ashed since traces of mineral matter are always found in them. Emphasis must be laid upon the necessity of conducting blanks on the solvents.

Sulphur in Fillers

20. The sulphur in fillers is determined in order to calculate the rubber by difference. It is carried out only on the fillers obtained on the filter paper, the sulphur in the ash from the filtrate and washings, being negligible.

Total Sulphur

21. Several methods for total sulphur were tried. The method given was found to yield accurate results.

Interpretation of Results

22. Emphasis is laid on the method of calculating the results. The saponifiable acetone extract and the unsaponifiable resins are considered to be parts of the rubber. The chloroform and alcoholic potash extracts, when within the limits specified, are also so considered. It has been explained that the proteid matter with the fillers has been allowed for, since it also is a part of the rubber. The fillers are calculated sulphur-free, so that the sulphur will not be subtracted twice. No allowance is made for the ash in the raw rubber as it is considered to be negligible. This method of calculation has to be adopted if the rubber found is to agree with that originally put into the compound.

Moisture

23. A determination of moisture is not given, as electrical tests will detect its presence if in excess. If electrical tests are required, the error introduced by the omission of this determination, is very small.

Note: With a procedure of this length it is impossible to explain every detail without undue elaboration and the Committee wishes to point out that while to experienced chemists the procedure may seem overburdened by detail, yet every specified detail was found necessary in order that the conditions essential to accurate and consistent work might be reproduced by all chemists using the procedure. For this reason it is extremely important that all instructions be observed even if their significance is not perceived by the individual chemist. It will probably be found that even with the instructions properly observed, some experience will be needed to apply the method successfully.

Part IV—Specification for 30 Per Cent Hevea Rubber Compound

1. A 30 per cent fine *Para* or smoked first latex *Hevea* rubber compound with mineral base, shall be furnished. It shall contain only the following ingredients:

Rubber.
Sulphur.
Inorganic mineral matter.
Refined solid paraffine or ceresine.

2. It shall not contain either red lead or carbon.

3. The vulcanized compound shall conform to the following requirements, when tested by the procedure of the Joint Rubber Insulation Committee.

(a) Results to be expressed as percentages by weight of the whole sample:

	Maximum	Minimum
Rubber	33	30
Waxy hydrocarbons	4	..
Free sulphur	0.7	..

(b) Results to be taken between the limits given in proportion to the percentage by weight of rubber found:

Limits allowed for 30 per cent Rubber Compound.	Maximum	Minimum
Saponifiable acetone extract	1.35	0.55
Unsaponifiable resins	0.45	....
Chloroform extract	0.90	....
Alcoholic potash extract	0.55	....
Total sulphur (see note 2)	2.10	....
Specific gravity	....	1.75
Limits allowed for 33 per cent Rubber Compound.		
Saponifiable acetone extract	1.50	0.60
Unsaponifiable resins	0.50	....
Chloroform extract	1.00	....
Alcoholic potash extract	0.60	....
Total sulphur (see note 2)	2.30	....
Specific gravity	....	1.67

4. The acetone solution shall not fluoresce.

5. The acetone extract (60 cu.cm.) shall be not darker than a light straw color.

6. Hydrocarbons shall be solid, waxy and not darker than a light brown.

7. Chloroform extract (60 cu.cm.) shall be not darker than a straw color.

8. Failure to meet any requirement of this specification will be considered sufficient cause for rejection.

9. Contamination of the compound, such as by the use of impregnated tapes, will not excuse the manufacturer from conforming to this specification.

Note 1: This specification shall be supplemented by appropriate clauses relating to tensile strength, elasticity, insulation resistance and dielectric strength.

Note 2: The limit on total sulphur may be omitted at the option of the purchaser. See Part V of Report.

PART V—EXPLANATION OF SPECIFICATION

1. Experience has shown that compounds which upon analysis, show the characteristics of good *Hevea* rubber, may be relied upon to be more permanent than those made of rubber of other grades. It is not affirmed by the Committee that a compound which conforms with this specification, is necessarily permanent, or that a better compound cannot be made, but it is believed that enforcement of the specification will limit the use of inferior materials and that it will put the manufacturers more nearly upon an equality of endeavor, where they can use their experience to obtain the best results. Used in connection with the analytical procedure, the specification will enable purchasers to order a good compound and to ascertain with a greater certainty than heretofore, whether the material received, represents the compound specified.

2. The term *Hevea* applied to rubber means rubber from the *Hevea Brasiliensis* tree whether wild or cultivated and regardless of the locality in which it has been grown. *Para* rubber is *Hevea* rubber which has been shipped from the port of Para, Brazil, and comes in several grades. Smoked first latex *Hevea* rubber is a high grade of plantation rubber which is collected prime and consists entirely of rubber which has risen in the settling vats. It is coagulated chemically and smoked in order to give it a hard cure, which ensures the greatest durability. The rubber required by this specification should be *Hevea* rubber of good quality, such a *fine Para* or smoked first latex plantation rubber.

3. Carbon is excluded because it is considered, by some purchasers, to be deleterious.

4. Red lead is excluded because of the possibilities of its deleterious effects on the rubber.

5. Ozokerite is prohibited because the acetone extract obtainable from it interferes with the separation of the acetone extract obtainable from the rubber, thereby vitiating the assay of the rubber extract. This prohibition is unimportant to the manufacturers, as ceresine, which is permitted, is the essential constituent of ozokerite.

6. An upper limit is placed upon the rubber in order to prevent the attainment of electrical and mechanical strength by the use of an extra quantity of inferior rubber whose lasting qualities might not be satisfactory.

7. The hydrocarbons are limited owing to their tendency to separate from the compound and thus possibly cause porosity.

8. The free sulphur is limited because an excessive amount may be deleterious.

9. The maximum limit on the saponifiable acetone extract is to prevent the use of raw or reclaimed rubber with high saponifiable extract. The minimum limit assists in forcing the use of *Hevea* rubber, since it is characteristic of the acetone extract from *Hevea* rubber to be largely saponifiable.

10. The unsaponifiable resins are limited because a low proportion of unsaponifiable resins is characteristic of *Hevea* rubber. A high result might be due to the presence of reclaimed rubber.

11. The chloroform extract is limited, first to prevent the use of bituminous substances, and second, to limit depolymerized and undercured rubber.

12. The alcoholic potash extract is limited to prevent the use of saponifiable rubber substitutes.

13. The specific gravity is limited to reconcile the specification of ingredients by weight with the practise of purchasing material by volume.

14. Fluorescence of the acetone solution is prohibited as it indicates the presence of mineral oils.

15. The color of the acetone extracts is specified to conform with the normal color of the extract from *Hevea* rubber. A darker color indicates adulteration or an inferior grade of rubber.

16. The hydrocarbons are required to be solid in order to prevent the use of oils and paraffine of low melting point. The shade required is that obtained from paraffine wax or ceresine. If hydrocarbons are liquid this would indicate reclaimed rubber softened with mineral oil, or a poor grade of paraffine.

17. The color of the chloroform extract is specified to conform with the color of dissolved gum in minute quantities. The presence of bituminous substances would be indicated by a brown or black color.

18. It would be desirable that the sulphur of vulcanization be limited to exclude reclaimed rubber, which contains the sulphur of its previous vulcanization, but the Committee has not yet developed an acceptable method for determining this quantity. It is, therefore, confronted with the choice of either placing a limit on the total sulphur or giving up the attempt to exclude shoddy by sulphur limitation. Option is therefore given to the purchaser to insert or omit the limit on total sulphur. Such insertion will at times exclude reclaimed rubber and the Committee believes it possible to make a suitable compound with this limitation. The Committee thinks that a sulphur limit positively excluding reclaimed rubber, would place too great a hardship, in other ways, on the manufacturers. Where the specification is used with no total sulphur limit, the use of many kinds of, or much, reclaimed rubber, will be guarded against by the limits of the various components of the acetone extract. When the limitation on total sulphur is omitted, sulphur-bearing fillers, which possess certain advantages, may be used.

19. This specification should be supplemented by appropriate elasticity and tensile strength tests, in order to add to the assurance that good rubber has been used and that the vulcanization process has been properly carried out; also by appropriate electric stress and resistance tests, to assure proper insulating qualities and homogeneity of structure. The exact values of the limits for these tests will depend upon the use to which the material is to be put.

JOINT RUBBER INSULATION COMMITTEE

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OCTOBER 1, 1913.

STANDARDIZATION RULES*

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

HISTORY OF THE STANDARDIZATION RULES

The first step taken by the Institute toward the standardization of electrical apparatus and methods was a topical discussion on " The Standardization of Generators, Motors and Transformers," which took place simultaneously in New York and Chicago on the evening of January 26, 1898. The discussion appears in the Institute TRANSACTIONS, Vol. XV, pages 3 to 32. The opinions expressed were generally favorable to the scheme of standardization of electrical apparatus, although some members feared that difficulties might arise. As a result of this discussion, a Committee on Standardization was appointed by the Council of the Institute, consisting of the following members:

FRANCIS B. CROCKER, *Chairman.*

CARY T. HUTCHINSON	CHARLES P. STEINMETZ
ARTHUR E. KENNELLY	LEWIS B. STILLWELL
JOHN W. LIEB, JR.	ELIHU THOMSON

After a careful consideration of the matter and consultation with the members of the Institute and interested parties generally, a "Report of the Committee on Standardization," was presented and accepted by the Institute, June 26, 1899. Those original rules appeared in the Institute TRANSACTIONS, Vol. XVI, pages 255 and 268.

As a result of changes and developments in the electric art, it was subsequently found necessary to revise the original report, this work being carried out by the following Committe on Standardization:

FRANCIS B. CROCKER, *Chairman.*

ARTHUR E. KENNELLY	CHARLES P. STEINMETZ
JOHN W. LIEB, JR.	LEWIS B. STILLWELL
C. O. MAILLOUX	ELIHU THOMSON

This revised report was adopted at the 19th Annual Convention at Great Barrington, Mass., on June 20, 1902, and appears in the Institute TRANSACTIONS, Vol. XIX, pages 1075 to 1092.

In consequence of still further change and development in electrical apparatus and methods, it was decided in September, 1905, that a second revision was needed, and the following Committee was appointed to do this work.

FRANCIS B. CROCKER, *Chairman.*
ARTHUR E. KENNELLY, *Secretary.*

HENRY S. CARHART	CHARLES F. SCOTT
JOHN W. LIEB, JR.	CHARLES P. STEINMETZ
C. O. MAILLOUX	HENRY G. STOTT
ROBERT B. OWENS	S. W. STRATTON

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*NOTE: This edition of the Standardization Rules, which became effective July 1, 1915, is a revision of the edition of December 1, 1914.

This Committee held monthly meetings and carried on extensive correspondence with manufacturers, consulting and operating engineers and other interested parties, and as a result, presented its report at the 23d Annual Convention, held at Milwaukee, May 28–30, 1906. After considerable discussion the report was accepted and referred back to the Committee for amendment and rearrangement in form. It was then to be submitted to the Board of Directors for final adoption. In September, 1906, the following Standardization Committee was appointed:

FRANCIS B. CROCKER, *Chairman.*
ARTHUR E. KENNELLY, *Secretary.*
A. W. BERRESFORD
DUGALD C. JACKSON
C. O. MAILLOUX
ROBERT B. OWENS
CHARLES F. SCOTT
CHARLES P. STEINMETZ
HENRY G. STOTT
S. W. STRATTON
ELIHU THOMSON

This Committee held monthly meetings, also sub-committee meetings, and carefully referred the rules as a whole, and each part of them, to the members of the Institute. The rules were also entirely rearranged as to form, and put in shape to facilitate ready reference to them and enable future revisions to be made without breaking up the logical arrangement. Thus amended the rules were submitted to the Board of Directors and approved by it on June 21, 1907. The Board also directed that the rules should be presented, as accepted by the Board, at the Annual Convention held at Niagara Falls, June 24 to 27, 1907, which action was taken by President Sheldon on June 26, 1907. By the Constitution which went into effect on June 10, 1907, this Committee has been made a standing Committee with the title "Standards Committee," consisting of nine members.

On August 12, 1910, the Board of Directors increased the size of the committee from nine to twelve members; on October 14 from twelve to fourteen, and on March 10, 1911, from fourteen to sixteen. The committee thus constituted is given below.

COMFORT A. ADAMS, *Chairman.*
ARTHUR E. KENNELLY, *Secretary.*
H. W. BUCK
GANO DUNN
H. W. FISHER
H. B. GEAR
J. P. JACKSON
W. L. MERRILL
RALPH D. MERSHON
W. S. MOODY
R. A. PHILIP
W. H. POWELL
CHARLES ROBBINS
E. B. ROSA
CHARLES P. STEINMETZ
CALVERT TOWNLEY

This committee and several sub-committees held numerous meetings at which the general revision of the Standardization Rules of the Institute was considered. The complete Standardization Rules, as revised by this committee, were presented to and approved by the Board of Directors on June 27, 1911, at the Annual Convention held at Chicago, Ill.

During the following two years (1911-1913) the Standards Committee, somewhat modified and enlarged, undertook a radical revision of the Rules, particularly in connection with the important subject of Rating. In August 1913 the Committee was still further enlarged by the Board of Directors in order to permit of comprehensive sub-committees for the various parts of the work. The Committee thus constituted is given as follows:

A. E. Kennelly, *Chairman.*
Comfort A. Adams, *Secretary.*

SUB-COMMITTEE No. 1. ON RATING.

H. M. Hobart, *Chairman.*

James Burke
W. C. L. Eglin
B. G. Lamme
W. A. Layman
W. L. Merrill
W. S. Moody
W. H. Powell
Charles Robbins
C. F. Scott
James M. Smith
Charles P. Steinmetz
J. Franklin Stevens
Philip Torchio

SUB-COMMITTEE No. 2. ON TELEGRAPH AND TELEPHONE STANDARDS.

F. B. Jewett, *Chairman.*

H. W. Fisher
F. F. Fowle
R. H. Marriott
J. H. Morecroft
J. M. Smith

SUB-COMMITTEE No. 3. ON RAILWAY STANDARDS.

W. A. Del Mar, *Chairman.*

F. W. Carter*
Hugh Hazelton*
E. R. Hill*
H. M. Hobart
William McClellan
Harold Pender
Martin Schreiber*
N. W. Storer*

SUB-COMMITTEE No. 4. ON NOMENCLATURE AND SYMBOLS

Comfort A. Adams, *Chairman.*

Louis Bell
Dugald C. Jackson
M. G. Lloyd
H. Pender
E. B. Rosa
A. S. McAllister
R. H. Marriott

SUB-COMMITTEE No. 5. ON WIRES AND CABLES.

H. W. Fisher, *Chairman.*

Wallace Clark
W. A. Del Mar
W. C. L. Eglin
E. B. Rosa
C. E. Skinner
S. W. Stratton

SUB-COMMITTEE NO. 6. ON RATING AND TESTING OF CONTROL APPARATUS.

L. T. Robinson, *Chairman.*

Morton Arendt
R. A. Carle
C. H. Sharp
P. H. Thomas
Philip Torchio

Sub-committee No. 1 had representation from the National Electric Light Association (Messrs. L. L. Elden, G. L. Knight, J. E. Kearns, and E. P. Dillon), from the Association of Edison Illuminating Companies (Mr. P. Torchio) and from the Electric Power Club (Messrs. James Burke and J. M. Smith).

Sub-committee No. 3, through Messrs. Schreiber and Del Mar, respectively, worked in collaboration with the Committees of the American Electric Railway Engineering Association, and the Association of Railway Electrical Engineers.

*Sub-committee No. 3 was a joint subcommittee of the Standards Committee and of the Railway Committee. The members opposite whose names occurs an asterisk, represented the latter committee.

The following members, although not appointed on the Standards Committee, have materially contributed to its work and have attended its meetings:

Carl J. Fechheimer, E. D. Priest, R. B. Williamson, K. A. Pauly, L. F. Blume, C. Renshaw, G. H. Hill, C. J. Hixson.

The radical revision begun in 1911 was completed by this Committee and approved by the Board of Directors at a special meeting held on July 10, 1914, subject to editorial revision by the Committee, and to go into force on Dec. 1, 1914.

The Committee of 1914-1915 which carried out the editorial revision, found it impossible to complete the work satisfactorily by Dec. 1st. The edition of July 1st, 1915, approved by the Board of Directors at its meeting of June 30, 1915, thus represents substantially the completion and clarification of the previous radical revision, although it includes a number of important additions. This Committee was constituted as follows:

A. E. KENNELLY, Chairman, Harvard University Cambridge, Mass.
C. A. ADAMS, Secretary, Harvard University, Cambridge, Mass.
JAMES BURKE, Erie, Pa.
W. A. DEL MAR, New York,
H. W. FISHER, Perth Amboy, N. J.
G. L. KNIGHT, Brooklyn, N. Y.
H. M. HOBART, Schenectady, N. Y.
F. B. JEWETT, New York.
P. JUNKERSFELD, Chicago, Ill.
W. L. MERRILL, Schenectady, N. Y.
W. H. POWELL, Milwaukee, Wis.
CHARLES ROBBINS, East Pittsburgh, Pa.
L. T. ROBINSON, Schenectady, N. Y.
E. B. ROSA, Washington, D. C.
C. E. SKINNER, East Pittsburgh, Pa.
J. M. SMITH, New York.
H. G. STOTT, New York.
P. H. THOMAS, New York.

NOTE.

The Standards Committee takes this occasion to draw the attention of the membership to the value of suggestions based upon experience gained in the application of the Rules to general practise.

Any suggestions looking toward improvement in the Rules should be communicated to the Secretary of the Institute, for the guidance of the Standards Committee in the preparation of future editions.

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PREFACE

In framing these rules, the chief purpose has been to define the terms and conditions which characterize the rating and behavior of electrical apparatus, with special reference to the conditions of acceptance tests.

It has not been the purpose of the rules to standardize the dimensions or details of construction of any apparatus, lest the progress of design and production should be hampered.

DEFINITIONS

NOTE. The following definitions are intended to be practically descriptive, rather than scientifically rigid.

CURRENT, E.M.F. and POWER.

(The definitions of currents given below apply also, in most cases, to electromotive force, potential difference, magnetic flux, etc.)

1 **Direct Current.** A unidirectional current. As ordinarily used, the term designates a practically non-pulsating current.

2 **Pulsating Current.** A current which pulsates regularly in magnitude. As ordinarily employed, the term refers to unidirectional current.

3 **Continuous Current.** A practically non-pulsating direct current.

4 **Alternating Current.** A current which alternates regularly in direction. Unless distinctly otherwise specified, the term "alternating current" refers to a periodic current with successive half waves of the same shape and area.

5 **Oscillating Current.** A periodic current whose frequency is determined by the constants of the circuit or circuits.

6 **Cycle.** One complete set of positive and negative values of an alternating current.

7 **Electrical Degree.** The 360th part of a cycle.

8 **Period.** The time required for the current to pass through one cycle.

9 **Frequency.** The number of cycles or periods per second. The product of 2π by the frequency is called the ***angular velocity*** of the current.

10 **Root-Mean-Square** or **Effective Value.** The square root of the mean of the squares of the instantaneous values for one complete cycle. It is usually abbreviated r.m.s. Unless otherwise specified, the numerical value of an alternating current refers to its r.m.s. value. The r.m.s. value of a sinusoidal wave is equal to its maximum, or crest value, divided by $\sqrt{2}$. The word "virtual" is sometimes used in place of r.m.s., particularly in Great Britain.

11 **Wave-Form** or **Wave-Shape.** The shape of the curve obtained when the instantaneous values of an alternating current are plotted against time in rectangular co-ordinates. The distance along the time axis corresponding to one complete cycle of values is taken as 2π radians, or 360 degrees. Two alternating quantities are said to have the same wave-form when their ordinates of corresponding phase (see § 13) bear a constant ratio to each other. The wave-shape, as thus understood, is therefore independent of the frequency of the current and of the scale to which the curve is represented.

12 **Simple Alternating** or **Sinusoidal Current.** One whose wave-shape is sinusoidal.

Alternating-current calculations are commonly based upon the assumption of sinusoidal currents and voltages.

13 **Phase.** The distance, usually in angular measure, of the base of any ordinate of an alternating wave from any chosen point on the time axis, is called the phase of this ordinate with respect to this point. In the case of a sinusoidal alternating quantity, the phase at any instant may be represented by the corresponding position of a line or *vector* revolving about a point with such an angular velocity ($\omega = 2\pi f$), that its projection at each instant upon a convenient reference line is proportional to the value of the quantity at that instant.

14 **Non-Sinusoidal Quantities.** Quantities that cannot be represented by vectors of constant length in a plane. The following definitions of phase, active component, reactive component, etc., are not in general applicable thereto. Certain "equivalent" values, as defined below, may, however, be used in many instances, for the purpose of approximate representation and calculation.

15 **Crest-Factor or Peak-Factor.** The ratio of the crest or maximum value to the r.m.s. value. The crest factor of a sine-wave is $\sqrt{2}$.

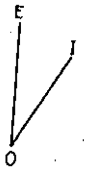
16 **Form Factor.** The ratio of the r.m.s. to the algebraic mean ordinate taken over a half-cycle beginning with the zero value. If the wave passes through zero more than twice during a single cycle, that zero shall be taken which gives the largest algebraic mean for the succeeding half-cycle. The form factor of a sine-wave is 1.11.

17 **The Distortion Factor of a wave.** The ratio of the r.m.s. value of the first derivative of the wave with respect to time, to the r.m.s. value of the first derivative of the equivalent sine wave.

18 **Equivalent Sine Wave.** A sine wave which has the same frequency and the same r.m.s. value as the actual wave.

*19 **Phase Difference: Lead and Lag.** When corresponding cyclic values of two sinusoidal alternating quantities of the same frequency occur at different instants, the two quantities are said to differ in phase by the angle between their nearest corresponding values; *e.g.*, the phase angle between their nearest ascending zeros or between their nearest positive maxima. That quantity whose maximum value occurs first in time is said to lead the other, and the latter is said to lag behind the former.

*20 **Counter-Clockwise Convention.** It is recommended that in any vector diagram, the leading vector be drawn counter-clockwise with respect to the lagging vector, † as in the accompanying diagram, where OI represents the vector of a current in a simple alternating-current circuit, lagging behind the vector OE of impressed e.m.f.



*21 **The Active or In-Phase Component** of the current in a circuit is that component which is in phase with the voltage across the circuit; similarly the active component of the voltage across a circuit is that component which is in phase with the current. The use of the term *energy component* for this quantity is disapproved.

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*Note: Definitions 19, 20, 21, 22, 23, 24, 25 refer strictly only to cases where the voltage and current are both sinusoidal (see §11 and 12).

†See Publication 12 of the International Electrotechnical Commission (Report of Turin Meeting, Sept. 1911, p. 78).

*22 **Reactive or Quadrature Component** of the current in a circuit. That component which is in quadrature with the voltage across the circuit; similarly, the reactive component of the voltage across the circuit is that component which is in quadrature with the current. The use of the term *wattless component* for this quantity is disapproved.

*23 **Reactive Factor.** The sine of the angular phase difference between voltage and current; *i. e.*, the ratio of the reactive current or voltage to the total current or voltage.

*24 **Reactive Volt-Amperes.** The product of the reactive component of the voltage by the total current, or of the reactive component of the current by the total voltage.

*25 **Non-Inductive Load and Inductive Load.** A *non-inductive* load is a load in which the current is in phase with the voltage across the load. An *inductive* load is a load in which the current lags behind the voltage across the load. A *condensive* or *anti-inductive* load is one in which the current leads the voltage across the load.

26 **Power in an Alternating-Current Circuit.** The average value of the products of the coincident instantaneous values of the current and voltage for a complete cycle, as indicated by a wattmeter.

27 **Volt-Amperes or Apparent Power.** The product of the r.m.s. value of the voltage across a circuit by the r.m.s. value of the current in the circuit. This is ordinarily expressed in kv-a.

28 **Power Factor.** The ratio of the power (cyclic average as defined in §26) to the volt-amperes. In the case of sinusoidal current and voltage, the power factor is equal to the cosine of their difference in phase.

29 **Equivalent Phase Difference.** When the current and e.m.f. in a given circuit are non-sinusoidal, it is customary, for purposes of calculation, to take as the "equivalent" phase difference, the angle whose cosine is the power factor (see §28) of the circuit. There are cases, however, where this equivalent phase difference is misleading, since the presence of harmonics in the voltage wave, current wave, or in both, may reduce the power factor without producing a corresponding displacement of the two wave forms with respect to each other; *e.g.*, the case of an a-c. arc. In such cases, the components of the equivalent sine waves, the equivalent reactive factor and the equivalent reactive volt-amperes may have no physical significance.

30 **Single-Phase.** A term characterizing a circuit energized by a single alternating e.m.f. Such a circuit is usually supplied through two wires. The currents in these two wires, counted positively outwards from the source, differ in phase by 180 degrees or a half-cycle.

31 **Three-Phase.** A term characterizing the combination of three circuits energized by alternating e.m.f.'s. which differ in phase by one-third of a cycle; *i.e.*, 120 degrees.

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*Note: Definitions 19, 20, 21, 22, 23, 24, 25 refer strictly only to cases where the voltage and current are both sinusoidal (see §11 and 12).

32 **Quarter-Phase, also called Two-Phase.** A term characterizing the combination of two circuits energized by alternating e.m.f's. which differ in phase by a quarter of a cycle; *i.e.*, 90 degrees.

33 **Six-Phase.** A term characterizing the combination of six circuits energized by alternating e.m.f's. which differ in phase by one sixth of a cycle; *i.e.*, 60 degrees.

34 **Polyphase.** A general term applied to any system of more than a single phase. This term is ordinarily applied to symmetrical systems.

Per Cent Drop.

50 In electrical machinery, the ratio of the **internal resistance drop** to the terminal voltage, expressed in per cent, is called the "*per cent resistance drop.*"

51 Similarly the ratio of the **internal reactance drop** to the terminal voltage, expressed in per cent, is called the "*per cent reactance drop.*"

52 Similarly the ratio of the **internal impedance drop** to the terminal voltage, expressed in per cent, is called the "*per cent impedance drop.*"

Unless otherwise specified, these per cent drops shall be referred to rated load and rated power factor.

53 **In the case of transformers,** the per cent drop will be the sum of the primary drop (reduced to secondary turns) and the secondary drop, in per cent of secondary terminal voltage.

54 **In the case of induction motors,** it is advantageous to express the drops in per cent of the internally induced e.m.f.

55 **The Load Factor** of a machine, plant or system. The ratio of the average power to the maximum power during a certain period of time. The average power is taken over a certain period of time, such as a day, a month, or a year, and the maximum is taken as the average over a short interval of the maximum load within that period.

In each case, the interval of maximum load and the period over which the average is taken should be definitely specified, such as a "half-hour monthly" load-factor. The proper interval and period are usually dependent upon local conditions and upon the purpose for which the load factor is to be used.

56 **Plant Factor.** The ratio of the average load to the rated capacity of the power plant, *i.e.*, to the aggregate ratings of the generators.

57 **The Demand** of an installation or system. The load which it puts on the source of supply, as measured at the receiving terminals. The demand may be as specified, contracted for, or used. It may be expressed either in kilowatts, kilovolt-amperes, amperes or other suitable units.

58 **The Maximum Demand** of an installation or system. Its greatest demand, as measured not instantaneously but averaged over a suitable and specified interval, such as a "five-minute maximum demand."

59 **Demand Factor.** The ratio of the maximum demand of any system or part of a system, to the total connected load of the system, or of the part of system, under consideration.

60 **Diversity Factor.** The ratio of the sum of the maximum power demands of the subdivisions of any system or parts of a system to the maximum demand of the whole system or of the part of the system under consideration, measured at the point of supply.

61 **Connected Load.** The combined continuous rating of all the receiving apparatus on consumers' premises, connected to the system or part of the system under consideration.

62 **The Saturation Factor of a machine.** The ratio of a small percentage increase in field excitation to the corresponding percentage increase in voltage thereby produced. Unless otherwise specified, the saturation factor of a machine refers to the no-load excitation required at normal rated speed and voltage. It is determined from measurements of saturation made on open circuit at rated speed.

63 **The Percentage Saturation** of a machine at any excitation may be found from its saturation curve of generated voltage as ordinates, against excitation as abscissas, by drawing a tangent to the curve at the ordinate corresponding to the assigned excitation, and extending the tangent to intercept the axis of ordinates drawn through the origin. The ratio of the intercept on this axis to the ordinate at the assigned excitation, when expressed in percentage, is the percentage of saturation and is independent of the scales selected for excitation and voltage. This ratio, as a fraction, is equal to the reciprocal of the saturation-factor at the same excitation, deducted from unity; or, if f be the saturation factor and p the percentage of saturation,

$$p = 100\left(1 - \frac{1}{f}\right)$$

64 **Magnetic Degree.** The 360th part of the angle subtended, at the axis of a machine, by a pair of its field poles. One mechanical degree is thus equal to as many magnetic degrees as there are pairs of poles in the machine.

65 **The Variation in Prime Movers** which do not give an absolutely uniform rate of rotation or speed, as in reciprocating steam engines, is the maximum angular displacement in position of the revolving member expressed in degrees, from the position it would occupy with uniform rotation, and with one revolution taken as 360 degrees.

66 **The Variation in Alternators** or alternating-current circuits in general, is the maximum angular displacement, expressed in electrical degrees, (one cycle = 360 deg.) of corresponding ordinates of the voltage wave and of a wave of absolutely constant frequency equal to the average frequency of the alternator or circuit in question, and may be due to the variation of the prime mover.

67 **Relations of Variations in Prime Mover and Alternator.** If p is the number of pairs of poles, the variation of an alternator is p times the variation of its prime mover, if direct-connected, and pn times the variation of the prime mover if rigidly connected thereto in such a manner that the angular speed of the alternator is n times that of the prime mover.

68 **The Pulsation in Prime Movers, or in the alternator connected thereto.** The ratio of the difference between the maximum and minimum velocities in an engine-cycle to the average velocity.

80 **Capacity.** The two different senses in which this word is used sometimes lead to ambiguity. It is therefore recommended that whenever such ambiguity is likely to arise, the descriptive term *power capacity* or *current capacity* be used, when referring to the power or current which a device can safely carry, and that the term "*Capacitance*" be used when referring to the electrostatic capacity of a device.

81 **Resistor.** A device, heretofore commonly known as a resistance, used for the operation, protection, or control of a circuit or circuits. See § 740.

82 **Reactor.** A coil, winding or conductor, heretofore commonly known as a reactance coil or choke coil, possessing inductance, the reactance of which is used for the operation, protection or control of a circuit or circuits. See also § 214 and 736.

83 **Efficiency.** The efficiency of an electrical machine or apparatus is the ratio of its useful output to its total input.

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TABLE I.

Symbols and Abbreviations.

Name of Quantity.	Symbol for the Quantity.	Unit.	Abbreviation for the Unit.
Electromotive force, abbreviated e.m.f.	E, e	volt	....
Potential difference, abbreviated p.d.	V, v or E, e	"	....
Voltage	E, e or V, v	"	....
Current	I, i	ampere	....
Quantity of electricity	Q, q	coulomb, ampere-hour	....
Power	P, p	watt	....
Electrostatic flux	Ψ	....	....
Electrostatic flux density	D	....	....
Electrostatic field intensity	F		....
Magnetic flux	Φ, φ	maxwell*	....
Magnetic flux density	$B, \mathcal{B}$	gauss*	....
Magnetic field intensity	$H, \mathcal{H}$	gilbert per centimeter or gauss†	gilbert per cm.
Magnetomotive force, abbreviated m.m.f.	$\mathfrak{F}$	gilbert*	....
Intensity of magnetization	J	....	....
Susceptibility	$\kappa = J/H$	....	....
Permeability	$\mu = B/H$	....	....

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* An additional unit for m. m. f. is the "ampere-turn", for flux the "line", for magnetic flux-density "maxwells per sq. in."

† The gauss is provisionally accepted for the present as the name of both the unit of field intensity and flux density, on the assumption that permeability is a simple numeric.

Resistance	R, r	ohm	....
Reactance	X, x	"	....
Impedance	Z, z	"	....
Conductance	g	mho	....
Susceptance	b	"	....
Admittance	Y, y	"	....
Resistivity	ρ	* ohm-centimeter	ohm-cm.
Conductivity	γ	*mho per centimeter	mho per cm.
Dielectric constant	ϵ or k	....	....
Reluctance	$\mathcal{R}$	....	....
Capacitance (Electrostatic capacity)	C	farad	....
Inductance (or coefficient of self induction)	L	henry	....
Mutual Inductance (or coefficient of mutual induction)	M	henry	....
Phase displacement	θ, φ	degree or radian	°
Frequency	f	cycle per second	~
Angular velocity	ω	radian per second	....
Velocity of rotation	n	revolution per second	rev. per sec.
Number of conductors or turns	N	convolution or turns of wire	
Temperature	T, t, θ	degree centigrade	°C
Energy, in general	U or W	joule, watt-hour	....
Mechanical work	W or A	joule, watt-hour	....
Efficiency	η	per cent	....
Length	l	centimeter	cm.
Mass	m	gram	g.
Time	t	second	sec.
Acceleration due to gravity	g	centimeter per second per second	cm. per sec. per sec.
Standard acceleration due to gravity (at about 45 deg. latitude and sea level) equals 980.665†	g_0	centimeter per second per second	cm. per sec. per sec.

**Note.* The numerical values of these quantities are *ohms resistance* and *mhos conductance* between two opposite faces of a cm. cube of the material in question, but the correct names are as given, not ohms and mhos per cm. cube, as commonly stated.

†This has been the accepted standard value for many years and was formerly considered to correspond accurately to 45° Latitude and sea level. Later researches, however, have shown that the most reliable value for 45° and sea-level is slightly different; but this does not affect the standard value given above.

91 E_m, I_m and P_m should be used for maximum cyclic values, e, i and p for instantaneous values, E and I for r.m.s. values (see §10) and P for the average value of the power, or the active power. These distinctions are not necessary in dealing with continuous-current circuits. In print, vector quantities should be represented by bold-face capitals.

CLASSIFICATION OF MACHINERY.

100 The machinery under consideration in these rules may be classified in various ways, these various classifications overlapping or interlocking in considerable degree. Briefly, they are Direct-Current or Alternating-Current, Rotating or Stationary. Under Rotating Apparatus there are two principal classifications: *First*, according to the function of the machines; Motors, Generators, Boosters, Motor-Generators, Dynamotors, Double-Current Generators, Converters and Phase Modifiers; *Second*, according to the type of construction or principle of operation; Commutating, Synchronous, Induction, Unipolar, Rectifying. Obviously, some of these machines could be rationally included in either classification, *e.g.*, Motor-Generators and Rectifying Machines.

In the following, self-evident definitions have for the most part, been omitted.

ROTATING MACHINES.

FUNCTIONAL CLASSIFICATION OF ROTATING MACHINES.

101 **Generator.** A machine which transforms mechanical power into electrical power.

102 **Motor.** A machine which transforms electrical power into mechanical power.

103 **Booster.** A generator inserted in series in a circuit to change its voltage. It may be driven by an electric motor (in which case it is termed a motor-booster) or otherwise.

104 **Motor-Generator Set.** A transforming device consisting of a motor mechanically coupled to one or more generators.

105 **Dynamotor.** A transforming device combining both motor and generator action in one magnetic field, either with two armatures, or with one armature having two separate windings and independent commutators.

106 **A Direct-Current Compensator or Balancer** comprises two or more similar direct-current machines (usually with shunt or compound excitation) directly coupled to each other and connected in series across the outer conductors of a multiple-wire system of distribution, for the purpose of maintaining the potentials of the intermediate wires of the system, which are connected to the junction points between the machines.

107 **A Double-Current Generator** supplies both direct and alternating currents from the same armature-winding.

108 **A Converter** is a machine employing mechanical rotation in changing electrical energy from one form into another. There are several types of converters as follow:

109 A **Direct-Current Converter** converts from a direct current to a direct current, usually with a change of voltage. Such a machine may be either a motor-generator set or a dynamotor.

110 A **Synchronous Converter** (sometimes called a Rotary Converter) converts from an alternating to a direct current, or vice-versa. It is a synchronous machine with a single closed-coil armature winding, a commutator and slip rings.

111 A **Cascade Converter,** also called a **Motor Converter,** is a combination of an induction motor with a synchronous converter, the secondary circuit of the former feeding directly into the armature of the latter; *i.e.*, it is a synchronous converter concatenated with an induction motor.

112 A **Frequency Converter** converts the power of an alternating-current system from one frequency to another, with or without a change in the number of phases, or in the voltage.

113 A **Rotary Phase-Converter** converts from an alternating-current system of one or more phases to an alternating-current system of a different number of phases, but of the same frequency.

114 A **Phase-Modifier,** also called *a Phase-Advancer*, is a machine which supplies reactive volt-amperes; *e.g.* to an induction motor, or to the system to which it is connected. Phase modifiers may be either synchronous or asynchronous.

115 A **Synchronous Phase-Modifier,** sometimes called a Synchronous Condenser, is a synchronous motor, running either idle or with load, the field excitation of which may be varied so as to modify the power-factor of the system, or through such modification to influence the load voltage. The function of a Synchronous Phase-Modifier is to supply reactive volt-amperes to the system with which it is connected.

CONSTRUCTIONAL CLASSIFICATION OF ROTATING MACHINES

Commutating Machines

130 **Direct-Current Commutating Machines** comprise a magnetic field of constant polarity, an armature, and a commutator connected therewith. These include: Direct-Current Generators; Direct-Current Motors; Direct-Current Boosters; Direct-Current Motor-Generator Sets and Dynamotors; Direct-Current Compensators or Balancers; and Arc Machines.

131 **Alternating-Current Commutating Machines*** comprise a magnetic field of alternating polarity, an armature, and commutator connected therewith.

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*Definitions of a-c. commutator-motors have not yet been agreed upon. The differences of opinion are fundamental and relate to the whole system to be employed in naming the numerous types. One example of this difference is in connection with the definition of the term "Repulsion-Motor", some desiring to extend its use to cover all a.c. commutator motors with short-circuited brushes, and others to substitute more systematic names for the various species of short-circuited brush motors.

132 **Synchronous Commutating Machines** include synchronous converters, cascade-converters, and double-current generators.

133 **Synchronous Machines** Comprise a constant magnetic field and an armature receiving or delivering alternating-currents in synchronism with the motion of the machine; *i.e.*, having a frequency strictly proportional to the speed of the machine. They may be sub-divided as follow:

134 **An Alternator** is a synchronous alternating-current generator, either single-phase or polyphase.

135 **A Polyphase Alternator** is a polyphase synchronous alternating-current generator, as distinguished from a **singlephase alternator.**

136 **An Inductor Alternator** is an Alternator in which both field and armature windings are stationary, and in which masses of iron or inductors, by moving past the coils, alter the magnetic flux through them. It may be either singlephase or polyphase.

137 **A Synchronous Motor** is a machine structurally identical with an alternator, but operated as a motor.

138 **Induction Machines** include apparatus wherein primary and secondary windings rotate with respect to each other; *i.e.*, induction motors, induction generators, certain types of frequency converters and certain types of rotary phase-converters.

139 **An Induction Motor** is an alternating-current motor, either singlephase or polyphase, comprising independent primary and secondary windings, one of which, usually the secondary, is on the rotating member. The secondary winding receives power from the primary by electromagnetic induction.

140 **An Induction Generator** is a machine structurally identical with an induction motor, but driven above synchronous speed as an alternating-current generator.

141 **Unipolar or Acyclic Machines** are direct-current machines, in which the voltage generated in the active conductors maintains the same direction with respect to those conductors.

SPEED CLASSIFICATION OF MOTORS.

150 Motors may, for convenience, be classified with reference to their speed characteristics as follow:

151 **Constant-Speed Motors,** whose speed is either constant or does not materially vary; such as synchronous motors, induction motors with small slip, and ordinary direct-current shunt motors.

152 **Multispeed Motors** two-speed, three-speed, etc.), which can be operated at any one of several distinct speeds, these speeds being practically independent of the load; such as motors with two armature windings, or induction motors in which the number of poles is changed by external means.

153 **Adjustable-Speed Motors,** in which the speed can be varied gradually over a considerable range, but when once adjusted remains practically unaffected by the load, such as shunt motors designed for a considerable range of speed variation.

154 **Varying-Speed Motors,** or motors in which the speed varies with the load, ordinarily decreasing when the load increases; such as series motors, compound-wound motors, and series-shunt motors. As a sub-class of varying-speed motors, may be cited, **adjustable varying-speed motors,** or motors in which the speed can be varied over a considerable range at any given load, but when once adjusted, varies with the load; such as compound-wound motors arranged for adjustment of speed by varying the strength of the shunt field.

CLASSIFICATION OF ROTATING MACHINES RELATIVE TO THE DEGREE OF ENCLOSURE OR PROTECTION

160 The following types are recognized:

- Open
- Protected
- Semi-enclosed
- Enclosed
- Separately ventilated
- Water-cooled
- Self-ventilated
- Drip-proof
- Moisture-resisting
- Submersible
- Explosion-proof
- Explosion-proof slip-ring enclosure

161 An **"open" machine** is of either the pedestal-bearing or end-bracket type where there is no restriction to ventilation, other than that necessitated by good mechanical construction.

162 A **"protected" machine** is one in which the armature, field coils, and other live parts are protected mechanically from accidental or careless contact, while free ventilation is not materially obstructed.

163 A **"semi-enclosed" machine** is one in which the ventilating openings in the frame are protected with wire screen, expanded metal, or other suitable perforated covers, having apertures not exceeding ½ of a square inch (3.2 sq. cm.) in area.

164 An **"enclosed" machine** is so completely enclosed by integral or auxiliary covers as to prevent a circulation of air between the inside and outside of its case, but not sufficiently to be termed air-tight.

165 A **"separately ventilated" machine** has its ventilating air supplied by an independent fan or blower external to the machine.

166 A **"water-cooled" machine** is one which mainly depends on water circulation for the removal of its heat.

167 A "**self-ventilated**" **machine** differs from a separately ventilated machine only in having its ventilating air circulated by a fan, blower, or centrifugal device integral with the machine.

If the heated air expelled from the machine is conveyed away through a pipe attached to the machine, this should be so stated.

168 A "**drip-proof**" **machine** is one so protected as to exclude falling moisture or dirt. A "drip proof" machine may be either "open" or "semi-enclosed", if it is provided with suitable protection integral with the machine, or so enclosed as to exclude effectively falling solid or liquid material.

169 A **moisture-resisting machine** is one in which all parts are treated with moisture-resisting material. Such a machine shall be capable of operating continuously or intermittently in a very humid atmosphere, such as in mines, evaporating rooms, etc.

170 A "**submersible**" **machine** is a machine capable of withstanding complete submersion, in fresh water or sea water, as may be specified, for four hours without injury.

171 An "**explosion-proof**" **machine** is a machine in which the enclosing case can withstand, without injury, any explosion of gas that may occur within it, and will not transmit the flame to any inflammable gas outside it.

172 An induction motor in which the slip rings and brushes alone are included within an explosion-proof case should not be described as an explosion-proof machine, but as a machine "with **explosion-proof slip-ring enclosure.**"

STATIONARY INDUCTION APPARATUS

200 **Stationary Induction Apparatus** changes electric energy to electric energy, through the medium of magnetic energy, without mechanical motion. It comprises several forms, distinguished as follow:

201 **Transformers**, in which the primary and secondary windings are ordinarily insulated one from another.

202 The terms "**high-voltage**" and "**low-voltage**" are used to distinguish the winding having the greater from that having the lesser number of turns. The terms "**primary**" and "**secondary**" serve to distinguish the windings in regard to energy flow, the primary being that which receives the energy from the supply circuit, and the secondary that which receives the energy by induction from the primary.

203 The **rated current of a constant-potential transformer** is that secondary current which, multiplied by the rated-load secondary voltage, gives the kv-a. rated output. That is, a transformer of given kv-a. rating must be capable of delivering the rated output at rated secondary voltage, while the primary impressed voltage is increased to whatever value is necessary to give rated secondary voltage.

The **Rated Primary Voltage** of a constant-potential transformer is the rated secondary voltage multiplied by the turn ratio.

204 The **ratio of a transformer**, unless otherwise specified, shall be the ratio of the number of turns in the high-voltage winding to that in the low-voltage winding; *i.e.*, the " turn-ratio."

205 The **voltage ratio** of a transformer is the ratio of the r.m.s. primary terminal voltage to the r.m.s. secondary terminal voltage, under specified conditions of load.

206 The " **current ratio** " of a current-transformer is the ratio of r.m.s. primary current to r.m.s. secondary current, under specified conditions of load.

207 The " **marked ratio** " of an instrument transformer is the ratio which the apparatus is designed to give under average conditions of use. When a precise ratio is required, it is necessary to specify the voltage, frequency, load and power factor of the load.

208 **Volt-Ampere Ratio of Transformers.**

The volt-ampere ratio, which should not be confused with real efficiency, is the ratio of the volt-ampere output to the volt-ampere input of a transformer, at any given power factor.

209 **Auto-transformers** have a part of their turns common to both primary and secondary circuits.

210 **Voltage Regulators** have turns in shunt and turns in series with the circuit, so arranged that the voltage ratio of the transformation or the phase relation between the circuit-voltages is variable at will. They are of the following three classes:

211 **Contact Voltage Regulators**, in which the number of turns in one or both of the coils is adjustable.

212 **Induction Voltage Regulators**, in which the relative positions of the primary and secondary coils are adjustable.

213 **Magneto Voltage Regulators**, in which the direction of the magnetic flux with respect to the coils is adjustable.

214 **Reactors**, heretofore commonly called **Reactance-Coils**, also called **Choke Coils**; a form of stationary induction apparatus used to supply reactance or to produce phase displacement. See also §82 and 736.

INSTRUMENTS

225 An **Ammeter** is an instrument for measuring current, indicating in amperes.

226 A **Voltmeter** is an instrument for measuring difference of potential, indicating in volts.

227 A **Crest Voltage Meter** is a voltmeter designed to indicate either the crest; *i.e.*, the maximum value, of an alternating voltage, or the r.m.s. value of the sinusoidal voltage having the same crest value.

288 A **Wattmeter** is an instrument for measuring electrical power, indicating in watts.

229 **Recording Ammeters, Voltmeters, Wattmeters, etc.**, are instruments which record graphically upon a time-chart the values of the quantities they measure.

230 A **Watt-hour Meter** is an instrument for registering watt-hours. This term is to be preferred to the term "integrating wattmeter."

231 A **Line-Drop Voltmeter Compensator** is a device used in connection with a voltmeter, which causes the latter to indicate the voltage at some distant point of the circuit.

232 A **Synchroscope,** sometimes called a **Synchronism Indicator,** is a device which, in addition to indicating synchronism, shows whether the incoming machine is fast or slow.

STANDARDS FOR ELECTRICAL MACHINERY

250 *The expressions " machinery " and " machines " are here employed in a general sense, in order to obviate the constant repetition of the words " machinery or induction apparatus."*

251 *All temperatures are to be understood as centigrade.*

252 *The expression " capacity " is to be understood as indicating " capability ", except where specifically qualified, as, for instance, in the case of allusions to electrostatic capacity, i. e., capacitance.*

253 *Wherever special rules are given for any particular type of machinery or apparatus (such as switches, railway motors, railway substation machinery, etc., these special rules shall be followed, notwithstanding any apparent conflict with the provisions of the more general sections. In the absence of special rules on any particular point, the general rules on this point shall be followed.*

260 **Objects of Standardization.** To ensure satisfactory results, electrical machinery should be specified to conform to the Institute Standardization Rules, in order that it shall comply, in operation, with approved limitations in the following respects, so far as they are applicable.

Operating temperature
Mechanical strength
Commutation
Dielectric strength
Insulation resistance
Efficiency
Power factor
Wave shape
Regulation

261 **Capacity or Available Output of an Electrical Machine.** So far as relates to the purposes of these Standardization Rules, the Institute defines the Capacity of an Electrical Machine as the load which it is capable of carrying for a specified time (or continuously), without exceeding in any respect the limitations herein set forth.

Except where otherwise specified, the capacity of an electrical machine shall be expressed in terms of its available *output.* For exceptions see §**277** and **802.**

262 **Rating of an Electrical Machine.** Capacity should be distinguished from Rating. The Rating of a machine is the output marked on the Rating Plate, and shall be based on, but shall not exceed, the maximum* load which can be taken from the machine under prescribed conditions of test. This is also called the rated output.

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*The term " maximum load " does not refer to loads applied solely for mechanical, commutation, or similar tests.

263 **The Principle upon which Machine Ratings** are based, so far as relates to thermal characteristics, is that the rated load, applied continuously or for a stated period, shall produce a temperature rise which, superimposed upon a standard ambient temperature, will not exceed the maximum safe operating temperature of the insulation.

264 **A. I. E. E. and I. E. C. Ratings.** When the prescribed conditions of test are those of the A. I. E. E. Standardization Rules, the rating of the machine is the Institute Rating. (See §620). When the prescribed conditions of the test are those of the I. E. C.† Rules, the rating of the machine is the I. E. C. rating. A machine so rated in either case may bear a distinctive sign upon its rating plate.

265 **Standard Temperature and Barometric Pressure for Institute Rating.** The Institute Rating of a machine shall be its capacity when operating with a cooling medium of the ambient temperature of reference (40° for air or 25° for water, see §305 and 309) and with barometric conditions within the range given in §308. See §320.

266 **The Temperatures Rises Specified in these Rules** apply to all ambient temperatures up to and including 40°C.

267 **Any Machinery Destined for Use with Higher Ambient** temperatures or cooling mediums, and also any machinery for operation at altitudes for which no provision is made in §308, should be the subject of special guarantee by the manufacturer. The methods of test and performance set forth in these Rules will, however, afford guidance in such cases.

UNITS IN WHICH RATING SHALL BE EXPRESSED

274 The rating of **Direct-Current Generators,** shall be expressed in kilowatts (kw.) available at the terminals.

275 The rating of **Alternators and Transformers,** shall be expressed in kilovolt-amperes (kv-a.) available at the terminals, at a specified power factor. The corresponding kilowatts should also preferably be stated.

276 It is strongly recommended that the **rating of motors** shall be expressed in kilowatts* (kw.) available at the shaft. (An ex-

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†I. E. C. stands for "International Electrotechnical Commission." This rating has not yet been established.

*Since the input of machinery of this class is measured in electrical units and since the output has a definite relation to the input, it is logical and desirable to measure the delivered power in the same units as are employed for the received power. Therefore, the output of motors should be expressed in kilowatts instead of in horse power. However, on account of the hitherto prevailing practice of expressing mechanical output in horse power, it is recommended that for machinery of this class the rating should, for the present, be expressed both in kilowatts and in horse power; as follows:

kw.————approx. equiv. h.p.————

The horse power rating of a motor may for practical purposes, be taken as 4/3 of the kilowatt rating.

In order to lay stress upon the preferred future basis, it is desirable that on Rating Plates, the Rating in kilowatts shall be shown in larger and more prominent characters than the rating in horse power.

ception to this rule is made in the case of Railway motors, which, for some purposes, are also rated by their *input*, see §802.)

277 **Auxiliary machinery,** such as regulators, resistors, reactors, balancer sets, stationary and synchronous condensers, etc., shall have their ratings appropriately expressed. It is essential to specify also the voltage (and frequency, if a-c.,), of the circuits on which the machinery may appropriately be used.

KINDS OF RATING

There are various kinds of rating such as:

281 **Continuous Rating.** A machine rated for continuous service; shall be able to operate continuously at its rated output, without exceeding any of the limitations referred to in §260.

282 **Short-Time Rating.** A machine rated for short-time service; (*i.e.* service including runs alternating with stoppages of sufficient duration to ensure substantial cooling), shall be able to operate at its rated output during a limited period, to be specified in each case, without exceeding any of the limitations referred to in §260. Such a rating is a **short-time rating.**

283 **Nominal Ratings.** For railway motors, and sometimes for railway-substation machinery, certain nominal ratings are employed. See 800 and §765.

284 **Duty-Cycle Operation.** Many machines are operated on a cycle of duty which repeats itself with more or less regularity. For purposes of rating, either a continuous or a short-time equivalent load, may be selected, which shall simulate as nearly as possible the thermal conditions of the actual duty cycle.

285 **Standard durations of equivalent tests** shall be for machines operating under specified duty-cycles as follow:

5 minutes
10 "
30 "
60 "
120 "
and continuous.

Of these the first five are short-time ratings, selected as being thermally equivalent to the specified duty cycle.

When, for example, a short-time rating of 10 minutes duration is adopted, and the thermally equivalent load is 25 kw. for that period, then such a machine shall be stated to have a 10-minute rating of 25 kw.

286 In every case the equivalent short-time test shall commence only when the windings and other parts of the machine are within 5°C of the ambient temperature at the time of starting the test.

287 In the absence of any specification as to the kind of rating, the continuous rating shall be understood.*

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*An exception is made in the case of motors for railway service, where in the absence of of any specification as to the kind of rating, the "nominal rating" as defined in §319 and 416 shall be understood.

288 Machines marked in accordance with **§264** shall be understood to have a continuous rating, unless otherwise marked in accordance with **§285**.

HEATING AND TEMPERATURE

300 **Temperature Limitations of the Capacity of Electrical Machinery.** The capacity, so far as relates to temperature, is usually limited by the maximum temperature at which the materials in the machine, especially those employed for insulation, may be operated for long periods without deterioration. When the safe limits are exceeded, deterioration is rapid. The insulating material becomes permanently damaged by excessive temperature, the damage increasing with the length of time that the excessive temperature is maintained, and with the amount of excess temperature, until finally the insulation breaks down.

301 The result of operating at temperatures in excess of the safe limit is to shorten the life of the insulating material. This shortening of life is, in certain special cases, warranted, when necessary for obtaining some other desirable result, as, for example, in some instances of railway and other motors for propelling vehicles, in providing greater power within a limited space. See **§804.** Further instances may also be noted in the cases of contactors, controllers, induction-starters, arc-lamp-magnet windings, etc., designed and constructed for operation at relatively high temperatures.

302 There does not appear to be any advantage in operating at lower temperatures than the safe limits, so far as the life of the insulation is concerned. Insulation may break down from various causes, and when these breakdowns occur, it is not usually due to the temperature at which the insulation has been operated, provided the safe limits have not been exceeded.

303 **The Ambient Temperature** is the temperature of the fluid or fluids which, coming into contact with the heated parts of a machine, carries off its heat convectively.

304 **The cooling fluid** may either be led to the machine through ducts, or through pipes, or merely surround the machine freely. In the former case the ambient temperature is to be measured at the intake of the machine itself. In the latter case see **§314.**

305 **Ambient Temperature of Reference for Air.** The standard ambient temperature of reference, when the cooling medium is air, shall be 40°C.

306 The permissible rises in temperature given in column 2 of table III in **§376** have been calculated on the basis of the standard ambient temperature of reference, by subtracting 40° from the highest temperatures permissible, which are given in column 1 of the same table.

307 A machine may be tested at any convenient ambient temperature, but whatever be the value of this ambient temperature, the

permissible rises of temperature must not exceed those given in column 2 of the table in §376.

308 **Altitude.** Increased altitude has the effect of increasing the temperature rise of some types of machinery. In the absence of information in regard to the height above sea level at which the machine is intended to work in ordinary service, this height is assumed not to exceed 1000 meters (3300 feet.) For machinery operating at an altitude of 1000 meters or less, a test at any altitude less than 1000 meters is satisfactory, and no correction shall be applied to the observed temperatures. Machines intended for operation at higher altitudes shall be regarded as special. See §267. It is recommended that when a machine is intended for service at altitudes above 1000 meters (3300 ft.) the permissible temperature rise at sea level, until more nearly accurate information is available, shall be reduced by 1 per cent for each 100 meters (330 ft.) by which the altitude exceeds 1000 meters. Water cooled oil transformers are exempt from this reduction.

309 **Ambient Temperature of Reference for Water-Cooled Machinery.** For water-cooled machinery, the standard temperature of reference for incoming cooling water shall be 25° C, measured at the intake of the machine.

310 **In the testing of water-cooled transformers,** it is not necessary to take into account the surrounding-air temperature, except where the cooling effect of the air is 15 per cent or more of the total cooling effect, referred to the standard ambient temperature of reference of 25°C. for water and 40°C. for air. When the effect of the cooling air is 15 per cent. or more of the total, the temperature of the cooling water should be maintained within 5°C. of the surrounding air. Where this is impractical, the ambient temperature should be determined from the change in the resistance of the windings, using a disconnected transformer, supplied with the normal amount of cooling water, until the temperature of the windings has become constant.

311 In the case of rotating machines, cooled by forced draught, a conventional weighted mean shall be employed, a weight of four being given to the temperature of the circulating air supplied through ducts (see §304), and a weight of one to the surrounding room air. **In the case of air-cooled transformers,** see "exception" §321.

312 **Machines Cooled by Other Means.** For machines cooled by other means, special rules are necessary.

313 **Outdoor Machinery Exposed to Sun's Rays.** Outdoor machinery not protected from the sun's rays at times of heavy load, must receive special consideration.

314 **Measurement of the Ambient Temperature During Tests of Machinery.** The ambient temperature is to be measured by means of several thermometers placed at different points around and half-way up the machine, at a distance of 1 to 2 meters (3 to 6 feet), and protected from drafts, and abnormal heat radiation, preferably as in §316.

315 The value to be adopted for the ambient temperature during a test, is the mean of the readings of the thermometers (placed as above), taken at equal intervals of time during the last quarter of the duration of the test.

316 In order to avoid errors due to the time lag between the temperature of large machines and the variations in the ambient air, all reasonable precautions must be taken to reduce these variations and the errors arising therefrom. Thus, the thermometer for determining the ambient temperature shall be immersed in a suitable liquid, such as oil, in a suitable heavy metal cup. This can be made to respond to various rates of change, by proportioning the amount of oil to the metal in the containing cup. A convenient form for such an oil-cup consists of a massive metal cylinder, with a hole drilled partly through it. This hole is filled with oil and the thermometer is placed therein with its bulb well immersed. The larger the machine under test, the larger should be the metal cylinder employed as an oil-cup in the determination of the ambient temperature. The smallest size of oil cup employed in any case shall consist of a metal cylinder 25 mm. in diameter and 50 mm. high (1 in. in diameter and 2 in high).

317 **Thermometers used for taking temperatures of Machinery** shall be covered by felt pads 3 mm. (⅛ inch) thick and 4 x 5 cm. wide (1½″x 2″), cemented on; oil putty may be used for stationary and small apparatus.

318 **In Transformer Testing,** and sometimes in testing other machines, it may be desirable to avoid errors due to time lag in temperature changes, by employing an idle unit of the same size and subjected to the same conditions of cooling as the unit under test, for obtaining the ambient temperature as described in §310.

319 Where **machines are partly below the floor line** in pits, the temperature of the rotor shall be referred to a weighted mean of the pit and room temperatures, the weight of each being based on the relative proportions of the rotor in and above the pit. Parts of the stator constantly in the pit shall be referred to the ambient temperature in the pit.

320 **Correction for the Deviation of the Ambient Temperature of the Cooling Medium, at the Time of the Heat Test, from the Standard Ambient Temperature of Reference.** Numerous experiments have shown that deviation of the temperature of the cooling medium from that of the standard of reference, at the time of the heat run, has a negligible effect upon the temperature rise of the apparatus; therefore, no correction shall be applied for this deviation. It is, however, desirable that tests should be conducted at ambient temperatures not lower than 20°C.

321 *Exception*—A Correction shall be applied to the observed temperature rise of the windings of *Air-blast transformers*, due to difference in resistance, when the temperature of the ingoing cooling air differs from that of the standard of reference. This correction

shall be the ratio of the inferred absolute ambient temperature of reference to the inferred absolute temperature of the ingoing cooling air, *i. e.* the ratio 274.5/(234.5 + t); where t is the ingoing cooling-air temperature.

Thus, a cooling-air room temperature of 30°C. would correspond to an inferred absolute temperature of 264.5° on the scale of copper resistivity, and the correction to 40°C. (274.5° inferred absolute temperature) would be 274.5 / 264.5 = 1.04, making the correction factor 1.04; so that an observed temperature rise of say 50°C. at the testing ambient temperature of 30°C. would be corrected to 50 × 1.04 = 52°C. this being the temperature rise which would have occurred had the test been made with the standard ingoing cooling-air temperature of 40°C.

322 **Duration of Temperature Test of Machine for Continuous Service.** The temperature test shall be continued until sufficient evidence is available to show that the maximum temperature and temperature rise would not exceed the requirements of the rules, if the test were prolonged until a steady final temperature was reached.

323 **Duration of Temperature Test of Machine with a Short-Time Rating.** The duration of the temperature test of a machine with a short-time rating shall be the time required by the rating. (See §285 and 286).

324 **Duration of Temperature Test for Machine having more than One Rating.** The duration of the temperature test for a machine with more than one rating shall be the time required by that rating which produces the greatest temperature rise. In cases where this cannot be determined beforehand, the machine shall be tested separately under each rating.

325 **Temperature Measurements during Heat Run.** Temperature measurements, when possible, shall be taken during operation, as well as when the machine is stopped. The highest figures thus obtained shall be adopted. In order to abridge the long heating period, in the case of large machines, reasonable overloads of current, during the preliminary period, are suggested for them.

TEMPERATURE MEASUREMENTS

340 **The Actual Temperatures attained** in the different parts of a machine, and not the rises in temperature, affect the life of the insulation of the machine. (See §300 to 302).

341 **The Temperatures in the Different Parts of a Machine** which it would be desirable to ascertain, are the maximum temperatures reached in those parts.

342 **Whatever may be the Ambient Temperature** when the machine is in service, the limits of the maximum observable temperature and of temperature rise specified in the rules should not be exceeded in service; for, if the maximum temperature be exceeded, the insulation may be endangered, and if the rise be exceeded, the excess load may lead to injury, by exceeding limits other than those of

temperature; such as commutation, stalling load and mechanical strength.

343 **As it is Usually Impossible to Determine the Maximum Temperature** attained in insulated windings, it is convenient to apply a correction to the observable temperature, so as to approximate the difference between the actual maximum temperature and the observable temperature by the method used. This correction, or margin of security, is provided to cover the errors due to fallibility in the location of the measuring devices, as well as inherent inaccuracies in measurement and methods.

344 **In Determining the Temperature of Different Parts of a Machine** three methods as provided. The appropriate method for any particular case is set forth below.

345 **Method No 1. Thermometer Method.**

This method consists in the determination of the temperature, by mercury or alcohol thermometers, by resistance thermometers, or by thermocouples, any of these instruments being applied to the hottest accessible part of the *completed* machine, as distinguished from the thermocouples or resistance coils embedded in the machine as described under Method No. 3.

346 **When Method No. 1 is Used,** the hottest-spot temperature for windings shall be estimated by adding a hottest-spot correction of 15°C to the highest temperature observed, in order to allow for the practical impossibility of locating any of the thermometers at the hottest spot.

347 *Exception.* When the thermometers are applied directly to the surfaces of bare windings, such as an edgewise strip conductor, or a cast copper winding, a hottest-spot correction of 5°C., instead of 15°C, shall be made. For commutators, collector rings, bare metallic surfaces not forming part of a winding, or for oil in which apparatus is immersed, no correction is to be applied.

348 **Method No. 2. Resistance Method.**

This method consists in the measurement of the temperature of windings by their increase in resistance, corrected* to the instant of shut-down when necessary. In the application of this method, careful thermometer measurements must also be made, whenever practicable without disassembling the machine†, in order to increase the probability of revealing the highest observable temperature. Which-ever measurement yields the higher temperature, that temperature shall be taken as the "highest observable" temperature and a hottest-spot correction of 10°C added thereto.

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*Whenever a sufficient time has elapsed between the instant of shut-down and the time of the final temperature measurement to permit the temperature to fall, suitable corrections shall be applied, so as to obtain as nearly as practicable the temperature at the instant of shut-down. This can sometimes be approximately effected by plotting a curve, with temperature readings as ordinates and times as abscissas, and extrapolating back to the instant of shut-down. In other instances, acceptable correction factors can be applied.

In cases where successive measurements show *increasing* temperatures after shut-down, the highest value shall be taken.

†As one of the few instances in which the thermometer check cannot be applied in Method No. 2, the rotor of a turbo-alternator may be cited.

349 **The Temperature Coefficient of Copper** shall be deduced from the formula $1/(234.5 + t)$. Thus, at an initial temperature $t = 40°C.$, the temperature co-efficient of increase in resistance per degree centigrade rise, is $1/(274.5) = 0.00364$. The following table, deduced from the formula, is given for convenience of reference.

TABLE II.

Temperature Coefficients of Copper Resistance.

Temperature of the winding, in degrees C. at which the initial resistance is measured.	Increase in resistance of copper per °C., per ohm of initial resistance.
0	0.00 427
5	0.00 418
10	0.00 409
15	0.00 401
20	0.00 393
25	0.00 385
30	0.00 378
35	0.00 371
40	0.00 364

350 **In Coils of Low Resistance,** where the joints and connections form a considerable part of the total resistance, the measurement of temperature by the resistance method shall not be used.

351 **The Temperature of the Windings of Transformers** is always to be ascertained by Method 2. In the case of air-blast transformers, it is especially important to place thermometers on the coils near the air outlet.

352* **Method No. 3. Embedded Temperature-Detector Method.** This method consists in the use of thermo-couples or resistance temperature detectors, located as nearly as possible at the estimated hottest spot. When method No. 3 is used, it shall, when required, be checked by method No. 2; the hottest spot shall then be taken to be the highest value by either method, the required correction factors (§348 and §356) being applied in each case.

353 **By Building into the Machine** suitably placed temperature detectors, a temperature not much less than that of the hottest spot will probably be disclosed. When these devices are adopted for such

temperature determinations, a liberal number shall be employed, and all reasonable efforts, consistent with safety, shall be made to locate them at the various places where the highest temperatures are likely to occur.

354 **Temperature-Detectors** should be placed in at least two separate locations. One of these should be between a coil-side* and the core, and one between the top and bottom coil-sides where two coil-sides per slot are used. Where only one coil-side per slot is used, one set of detectors shall be placed between coil-side and core, and one between coil-side and wedge.

355 Method No. 3 should be applied to all stators of machines with cores having a width of 50 cm. (20 in.) and over. It should also be applied to all machines of 5000 volts and over, if of over 5000 kv-a., regardless of core width. This method is not required for induction-regulators, which shall be tested as transformers.

356 **Correction Factor for Method No. 3.**—In the case of two-layer windings, with detectors between coil-sides, and between coil-side and core, add 5° C to the highest reading. In single-layer windings, with detectors between coil-side and core and between coil-side and wedge, add to the highest reading 10° C. plus 1° C. per 1000 volts above 5000 volts of terminal pressure.

TEMPERATURE LIMITS

375 Table III gives the limits for the hottest-spot temperatures of insulations. The permissible limits are indicated in column 1 of the Table. The limits of temperature rise permitted under rated-load conditions are given in column 2, and are found by subtracting 40° C. from the figures in column 1. Whatever be the ambient temperature at the time of the test, the rise of temperature must never exceed the limits in column 2 of the table. The highest temperatures, and temperature rises, attained in any machine at the output for which it is rated, must not exceed the values indicated in the Table and clauses following.

376 **Permissible Temperatures and Temperature Rises For Insulating Materials.** Table III (see next page) gives the highest temperatures and temperature rises to which various classes of insulating materials may be subjected, based on a standard ambient temperature of reference of 40°C.

377 Note. The Institute recognizes the ability of manufacturers to employ Class B insulation successfully at maximum temperatures of 150° C. and even higher. However, as sufficient data covering experience over a period of years at such temperatures are at present unavailable, the Institute adopts 125° C as a conservative limit for this class of insulation, and any increase above this figure should be the subject of special guarantee by the manufacturer.

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*A coil-side is one of the two active sides of a coil.

TABLE III.

Permissible Temperatures and Temperature Rises for Insulating Materials.

Class	Description of Material	1 Maximum Temperature to which the material may be subjected	2 Maximum Temperature Rise
A.	Cotton, silk, paper and similar materials, when so treated or impregnated as to increase the thermal limit, or when permanently immersed in oil; also enamelled wire*...............	105°C	65°C
B.	Mica, asbestos and other materials capable of resisting high temperatures, in which any Class A. material or binder is used for structural purposes only, and may be destroyed without impairing the insulating or mechanical qualities of the insulation	125°C	85°C
C.	Fireproof and refractory materials, such as pure mica, porcelain, quartz, etc	No limits specified.	

*For cotton, silk, paper and similar materials, when neither impregnated nor immersed in oil, the highest temperatures and temperature rises shall be 10°C below the limits fixed for Class A, in Table III.

378 When a lower-temperature class material is comprised in a completed product to such an extent, or in such ways, that its subjection to the temperature limits allowed for the higher-temperature class material, with which it is associated, would affect the integrity of the insulation either mechanically or electrically, the permissible temperature shall be fixed at such a value as shall afford ample assurance that no part of the lower-temperature class material shall be subjected to temperatures higher than those approved by the Institute and set forth above.

379 TABLE IV

Permissible Hottest Spot Temperatures and Limiting Observable Temperature Rises in Other than Water-Cooled Machinery

		Class	A†	B
		Permissible Hottest-Spot Temperature....	105°	125°
METHOD I THERMOMETER ONLY See §345 to 347		Hottest Spot Correction.................	15°	15°
		Limiting Observable Temperature........	90°	110°
		Limiting Observable Temperature Rise above 40°C.......................	50°	70°
METHOD II RESISTANCE See §348		Hottest Spot Correction.................	10°	10°
		Limiting Observable Temperature........	95°	115°
		Limiting Observable Temperature Rise above 40°C.....................	55°	75°
METHOD III EMBEDDED TEMPERATURE DETECTORS See § 352 to §356	Double-Layer Windings. For all Voltages	Hottest Spot Correction.......	5°	5°
		Limiting Observable Temperature.................	100°	120°
		Limiting Observable Temperature Rise above 40°C...	60°	80°
	Single-Layer Windings. For 5000 volts or less	Hottest Spot Correction.......	10°	10°
		Limiting Observable Temperature.................	95°	115°
		Limiting Observable Temperature Rise above 40°C...	55°	75°
	Single-Layer Windings. For more than 5000 Volts	Hottest Spot Correction	10° + $(E-5)$*	10° + $(E-5)$
		Limiting Observable Temperature.................	95° − $(E-5)$	115° − $(E-5)$
		Limiting Observable Temperature Rise above 40°C...	55° − $(E-5)$	75° − $(E-5)$

†For cotton, silk, paper and similar materials, when neither impreganted nor immersed in oil, the highest temperatures and temperature rise shall be 10°C. below the limits fixed for class A.

*In these formulas, E represents the rated pressure between terminals in kilovolts. Thus for a three-phase machine with single-layer winding, and with 11 kilovolts between terminals, the hottest-spot correction to be added to the maximum observable temperature will be 16°C.

Special Cases of Temperature limits.

385 Temperature of Oil. The oil in which apparatus is permanently immersed shall in no part have a temperature, observable by thermometer, in excess of 90°C.

386 **Water-Cooled Transformers.** In these the hottest-spot temperature shall not exceed 90°C.

387 **Railway Motor Temperature Limits,** see §804 and **805**.

388 **Squirrel-Cage and Amortisseur Windings.** In many cases the insulation of such windings is largely for the purpose of making the conductors fit tightly in their slots, and the slightest effective insulation is ample. In other cases, there is practically no insulating material on the windings. Consequently, the temperature rise may be of any value such as will not occasion mechanical injury to the machine.

389 **Collector Rings.** The temperature of collector rings shall not be permitted to exceed the " hottest-spot " values set forth in §**376** and **379** for the insulations employed either in the collector rings themselves or in adjacent insulations whose life would be affected by the heat from the collector rings.

390 **Commutators.** The observable temperature shall in no case be permitted to exceed the values given in §**376** and **379** for the insulation employed, either in the commutator or in any insulation whose life would be affected by the heat of the commutator.

391 **Cores.** The temperature of those parts of the iron core in contact with insulating materials must not be such as to occasion in those insulating materials temperatures or temperature rises in excess of those set forth in §**376** and **379**.

392 **Other parts,** (such as brush-holders, brushes, bearings, pole-tips, cores, etc.) All parts of electrical machinery other than those whose temperature affects the temperature of the insulating material, may be operated at such temperatures as shall not be injurious in any respect.

METHODS OF LOADING TRANSFORMERS FOR TEMPERATURE TESTS

393 Whenever practicable, transformers should be tested under conditions that will give losses approximating as nearly as possible to those obtained under normal or specified load conditions, maintained for the required time (See §**322** to **324**). The maximum temperature rises measured during this test should be considered as the observable temperature rises for the given load.

An approved method of making these tests is the "**loading-back**" method. The principal variations of this method are—

394 **With duplicate single-phase transformers.**

Duplicate single-phase transformers may be tested in banks of two, with both primary and secondary windings connected in parallel. Normal magnetizing voltage should then be applied and the required current circulated from an auxiliary source. One transformer can be held under normal voltage and current conditions, while the other may be operating under slightly abnormal conditions.

395 **With one three-phase transformer.**

One three-phase transformer may be tested in a manner similar to (a), provided the primary and secondary windings are each connected in delta for the test. Normal three-phase magnetizing voltage should be applied and the required current circulated from an auxiliary single-phase source.

396 **With three single-phase transformers.**

Duplicate single-phase transformers may be tested in banks of three, in a manner similar to (b) by connecting both primary and secondary windings in delta, and applying normal three-phase magnetizing voltage and circulating the required current from an auxiliary single-phase source.

397 Note:— Among other methods that have a limited application and can be used only under special conditions may be mentioned—

(1) Applying dead load by means of some form of rheostat.

(2) Running alternately for certain short intervals of time on open circuit and then on short circuit, alternating in this way until the transformer reaches steady temperature. In this test, the voltage for the open-circuit interval and the current for the short-circuit interval shall be such as to give the same integrated core loss, and the same integrated copper loss, as in normal operation.

ADDITIONAL REQUIREMENTS

398 **Short-Circuit Stresses.**

The Institute recognizes the self-destructibility, both mechanical and thermal, of certain sizes and types of machines, when subjected to severe short-circuits, and recommends that ample protection be provided in such cases, external to the machine if necessary.

Over-Speeds.

399 All **Types of Rotating Machines** shall be so constructed that they will safely withstand an over-speed of 25 per cent, except in the case of steam turbines, which, when equipped with emergency governors, shall be constructed to withstand 20 per cent over-speed.

400 In the case of **Series Motors,** it is impracticable to specify percentage values for the guaranteed over-speed, on account of the varying service conditions.

401 **Water-wheel Generators** shall be constructed for the maximum runaway speed which can be attained by the combined unit.

Momentary Loads.

402 **Continuously Rated Machines** shall be required to carry momentary loads of 150 per cent of the amperes corresponding to the continuous rating, keeping the rheostat set for rated load excitation, (See §**281**, **764** and **803**.) and commutating machinery shall commutate successfully under this condition. Successful commutation is such that neither brushes nor commutator are injured by the test. In the case of direct-connected generators, this clause is not to be interpreted as requiring the prime mover to drive the generator at this overload.

403 **Machines for duty-cycle operation** shall be rated according to their equivalent load, either on the short-time or continuous basis, but if intended for operation with widely fluctuating loads, shall commutate successfully under their specified operating conditions. See § **284, 285.**

404 **Stalling Torque of Motors**

Motors for continuous service shall, except when otherwise specified, be required to develop a running torque at least **175** per cent of that corresponding to the running torque at their rated load, without stalling.

Obviously, duty-cycle machines must carry their peak loads without stalling.

WAVE FORM

405 The **Sine Wave** shall be considered as standard, except where deviation therefrom is inherent in the operation of the system of which the machine forms a part.

406 **The deviation of wave form** from the sinusoidal is determined by superposing upon the actual wave, (as determined by oscillograph), the equivalent sine wave of equal length, in such a manner as to give the least difference, and then dividing the maximum difference between corresponding ordinates by the maximum value of the equivalent sine wave. A maximum deviation of the wave from sinusoidal shape not exceeding 10 per cent is permissible, except when otherwise specified.

EFFICIENCY AND LOSSES

420 **Machine Efficiency** is the ratio of the power delivered by the machine to the power received by it.

421 **Plant Efficiency** is the ratio of the energy delivered from the plant to the energy received by it in the a specified period of time.*

422 Two efficiencies are recognized, conventional efficiency and directly-measured efficiency. Unless otherwise specified, the conventional efficiency is to be employed.

423 **Conventional Efficiency** of machinery is the ratio of the output to the sum of the output and the losses; or of the input minus the losses to the input; when, in either case, conventional values are assigned to one or more of these losses. The need for assigning conventional values to certain losses, arises from the fact that some of the losses in electrical machinery are practicably indeterminable, and must, in many cases, either be approximated by an approved method of test or else values recommended by the Institute and designated "conventional" values shall be employed for them in arriving at the "conventional efficiency."

424 **Efficiencies based upon Conventional Losses** shall be specifically stated to be conventional efficiencies.

425 **Directly-Measured Efficiency.** Input and output determinations of efficiency may be made directly, measuring the output by brake,

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*An exception should be noted in the case of the efficiency of storage batteries.

or equivalent, where applicable. Within the limits of practical application, the circulating-power method, sometimes described as the Hopkinson or "loading-back" method, may be used.

426 **Values of the Indeterminate Losses** may also be obtained by brake or other direct test, and used in estimating actual efficiencies of similar machines, by the separate-loss method.

427 **Normal Conditions.** The efficiency shall correspond to, or be corrected to, the normal conditions herein set forth, which shall be regarded as standard. These conditions include voltage, current, power-factor, frequency, wave-shape, speed, temperature, or such of them as may apply in each particular case.

428 **Measurement of Efficiency.** Electric power shall be measured at the terminals of the apparatus. In polyphase machines, sufficient measurements shall be made on all phases to avoid errors of unbalance.

429 **Point at Which Mechanical Power Shall be Measured.** Mechanical power delivered by machines, shall be measured at the pulley, gearing, or coupling, on the rotor shaft, thus excluding the loss of power in the belt or gear friction. See, however, an exception in §800.

430 **The Efficiency of Alternating-Current machinery** shall be measured when the current is in phase with the terminal voltage, unless otherwise specified, or unless a definite phase difference is inherent in the apparatus, as in induction machinery.

431 **Efficiency of Alternating-Current Machinery in regard to WaveShape.** In determining the efficiency of alternating-current machinery, the sine wave is to be considered as standard, unless a different wave form is inherent in the operation of the system. See §405.

432 **Temperature of Reference for Efficiency Determinations.** The efficiency, at all loads, of all apparatus, shall be corrected to a reference temperature of 75°C.

433 **The losses in constant-potential machinery,** either of the stationary type, or of the constant-speed rotary type, are of two classes; namely, those which remain substantially constant at all loads, and those which vary with the load. The former include iron losses, windage and friction, also I^2R losses in any shunt windings. The latter include I^2R losses in series windings. The constant losses may be determined by measuring the power required to operate the machine at no load, deducting any series I^2R losses. The variable loss at any load may be computed from the measured resistance of the series windings and the given load current.

434 **Stray Load Losses.** The above simple method of determining the losses and hence the efficiency is only approximate, since the losses which are assumed to be constant do actually vary to some extent with the load, and also because the actual loss in the copper windings is sometimes appreciably greater than the calculated I^2R loss. The difference between the approximate losses, as above determined, and the actual losses, is termed the "stray load losses"*.

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*In Table V, the stray load losses include f, h, i, k, l and m; but do not include increased core losses due to increased excitation for compensating internal drop under load.

These latter are due to distortions in electric or magnetic fluxes from their no-load distributions or values, brought about by the load current. They are usually only approximately measurable, or may be indeterminable.

TABLE V

Classification of Losses in Machinery

435 Losses in machinery may be classified as follows:

Accurately Measurable or Determinable	*Approximately Measurable or Determinable*	*Indeterminable*
a. No-Load Core Losses including eddy-current losses in conductors at no-load	*c*. Brush Friction Loss	*h*. Iron Loss due to flux distortion.
b. Load I^2R losses in windings No-Load I^2R " " "	*d*. Brush-Contact Loss	*i*. Eddy-Current losses in conductors due to transverse fluxes occasioned by the load currents.
	e. Losses due to windage and to bearing friction	*k*. Eddy-Current losses in conductors due to tooth saturation resulting from distortion of the main flux.
	f. Extra copper loss in transformer windings, due to stray fluxes caused by load currents	*l* Tooth-frequency losses due to flux distortion under load.
	g. Dielectric Losses.	*m*. Short-Circuit Loss of Commutation.

436 **Evaluation of Losses.** The larger individual losses are either accurately or approximately determinable, but certain of the indeterminable losses reach values in various kinds of machinery which require that they should be taken into account.

Methods of measuring, approximating or allowing for these various losses are given below.

LOSSES TO BE TAKEN INTO ACCOUNT IN VARIOUS TYPES OF MACHINES

440 **Direct-Current Commutating Motors and Generators.**

No-load core losses. (Accurately Measurable or Determinable).

I^2R loss in all windings. (Acc. Meas. or Deter.)

Brush contact I^2R loss. (Approximately Meas. or Deter). Unless otherwise specified, use the Institute Standard of 1 volt for contact drop per brush; *i. e.*, 2 volts for total brush drop, for either carbon or graphite brushes. See **§454** and **819.**

Friction of bearings and windage. (Approx. Meas. or Deter.)

Rheostat losses, when present. (Acc. Meas. or Deter.)

Brush friction. (Approx. Meas. or Deter.)

All indeterminable load losses (including stray-load iron losses) which may be important, which vary with the design, and for which no satisfactory method of determination has been found, shall be included as zero per cent in estimating conventional efficiency.

441 **Synchronous Motors and Generators.**

No-load core losses. (Acc. Meas. or Deter.)

I^2R loss in all windings. (Acc. Meas. or Deter.) based upon rated kw. and power factor.

Stray load-losses. (Indeterminable.) In approximating these losses, the method described in **§458** shall be employed.

Friction of bearings and windage. (Approx. Meas. or Deter.)

Brush friction and brush-contact loss is negligible.

Rheostat losses, when present, corresponding to rated kw. and power factor. (Acc. Meas. or Deter.)

442 **Induction Machines.**

No-load core losses. (Acc. Meas. or Deter.)

I^2R losses in all windings. (Acc. Meas. or Deter.)

Stray load-losses. (Indeterminable.) In approximating these losses, the method described in **§459** shall be employed.

Brush friction when collector rings are present. (Approx. Meas. or Deter.)

Brush-contact loss. (Approximately Meas. or Deter.). Unless otherwise specified, use the Institute Standard of 1 volt for contact drop per brush, for either carbon or graphite brushes. See **§454.**

Friction of bearings and windage (Approx. Meas. or Deter.)

443 **Commutating A-C. Machines**

No-load core losses. (Acc. Meas. or Deter.)

I^2R losses in all windings. (Acc. Meas. or Deter.)

Brush friction. (Approx. Meas. or Deter.)

Brush-contact loss. (Approx. Meas. or Deter.) Unless otherwise specified, use the Institute Standard of 1 volt for contact drop per brush, for either carbon or graphite brushes. See **§454** and **819.**

Friction of bearings and windage. (Approx. Meas. or Deter.)

Short-Circuit loss of commutation. (Indeterminable.)

Iron loss due to flux distortion. (Indeterminable.)

Eddy-current losses due to fluxes varying with load and saturation. (Indeterminable.)

The Institute is not at this time prepared to make recommendations for approximating these losses.

444 **Synchronous Converters.**

No-load core losses. (Acc. Meas. or Deter.)

I^2R losses in all windings, based on rated kw. and power factor. (Approx. Meas. or Deter.) The I^2R losses in the armature winding shall be derived from those corresponding to its use as a direct-current generator, by using recognized factors.

Brush friction. (Approx. Meas. or Deter.)

Rheostat losses when present, corresponding to rated kw. and power factor. (Acc. Meas. or Deter.)

Brush-contact loss. (Approx. Meas. or Deter.) Unless otherwise specified, use the Institute Standard of 1 volt for contact drop per brush,—for either carbon or graphite brushes. See §454.

Short-circuit loss of commutation. (Indeterminable)

Iron loss due to flux distortion when present. (Indeterminable).

Eddy-current losses due to fluxes varying with load and saturation. (Indeterminable.)

These losses, while usually of low magnitude, are erratic, and the Institute is not at this time prepared to make recommendations for approximating them.

Friction of bearings and windage. (Approx. Meas. or Deter.)

For the booster type of synchronous converter, where the booster forms an integral part of the unit, its losses shall be included in the total converter losses in estimating the efficiency.

445 **Transformers.**

No-load losses. These include the core loss and the I^2R loss due to the exciting current, (Acc. Meas. or Deter.) also the dielectric hysteresis loss in the insulation, (Approx. Meas. or Deter.) (See §470.)

I^2R losses in all windings. (Acc. Meas. or Deter.)

Stray load losses. (Approx. Meas. or Deter.). These include eddy-current losses in windings and core, due to fluxes varying with load. See §471, for the method of approximating these losses.

DETERMINATION OR APPROXIMATION OF LOSSES IN ROTATING MACHINERY

450 **Bearing Friction and Windage** may be determined as follows. Drive the machine from an independent motor, the output of which shall be suitably determined. The machine under test shall have its brushes removed and shall not be excited. This output represents the bearing friction and windage of the machine under test.

The bearing friction and windage of induction motors may be measured by running motors free at the lowest voltage at which they will rotate continuously at approximately rated speed; the watts input, minus I^2R loss, under these conditions being taken as the friction and windage.

In the case of engine-type generators, the windage and bearing friction loss is ordinarily very small, amounting to a fraction of one per cent of the output. In these rules this loss is neglected owing to its small value and the difficulty of measuring it.

451 **Brush Friction of Commutator and Collector Rings.** Follow the test of **§450,** taking an additional reading with the brushes in contact with the commutator or collector rings. The difference between the output obtained in the test in **§450** and this output shall be taken as the brush friction. Note: The surfaces of the commutator and brushes should already be smooth and glazed from running when this test is made.

452 **No-Load Core Loss.** Follow the test in §451 with an additional reading taken with the machine excited. The difference between the output value of **§451** and the output value of this reading shall be taken as the no-load core loss. This no-load core loss shall be taken with the machine so excited, as to produce rated terminal voltage.

The Core Loss of Induction Motors may be determined by measuring the watts input to the motor when running free at normal rated voltage and frequency, and subtracting therefrom the no-load copper loss and the bearing friction and windage.

453 **No-Load Core Loss at the Internal Voltage Corresponding to Rated Load.** This shall be taken as in **§452,** except that the machine shall be so excited as to produce at the terminals the voltage corresponding to the calculated internal voltage for the load and power factor under consideration. For synchronous machines, since no generally accepted method is available for obtaining the stator reactance, the internal voltage shall be determined by correcting the terminal voltage for only the resistance drop.

454 **The Brush-Contact I^2R Loss** depends largely upon the material of which the brush is composed. As indicating the range of variation the following table will be of interest:

TABLE VI.

Brush-Contact Drop.

Grade of Brush	Volts drop across one brush-contact. (Average of positive and negative brushes)
Hard Carbon	1.1
Soft Carbon	0.9
Graphite	0.5 to 0.8
Metal-Graphite types	0.15 to 0.5 (The former for largest proportion of metal)

One volt drop per brush shall be considered as the Institute Standard drop corresponding to the I^2R brush-contact loss, for carbon and graphite brushes. Metal-graphite brushes shall be considered as special. See §810.

455 **Field-Rheostat Losses** shall be included in the generator losses where there is a field rheostat in series with the field magnets of the generator, even when the machine is separately excited.

456 **Ventilating Blower.** When a blower is supplied as part of a machine set, the power required to drive it shall be charged against the complete unit; but not against the machine alone.

457 **Losses in Other Auxiliary Apparatus.** Auxiliary apparatus, such as a separate exciter for a generator or motor, shall have its losses charged against the plant of which the generator and exciter are a part, and not against the generator. An exception should be noted in the case of turbo-generator sets with direct-connected exciters, in which case the losses in the exciter shall be charged against the generator. The actual energy of excitation and the field-rheostat losses, if any, (see §455) shall be charged against the generator.

458 **Stray Load-Losses in Synchronous Generators and Motors.** These include iron losses, and eddy-current losses in the copper, due to fluxes varying with load and also to saturation.

Stray load-losses are to be determined by operating the machine on short circuit and at rated-load current. This, after deducting the windage and friction and I^2R loss, gives the stray load-loss for polyphase generators and motors. These losses in single-phase machines are large; but the Institute is not yet prepared to specify a method for measuring them.

459 **Stray Load-Losses in Induction Machines.**

These include eddy-current losses in the stator copper, and other eddy-current losses due to fluxes varying with the load. In windings consisting of relatively small conductors, these eddy-current losses are usually negligible.

With rotor removed, and for a given stator current, measure the input the stator at different frequencies. Plot a curve of loss against frequency. At low frequencies, the loss becomes constant, indicating the I^2R value. The difference between this I^2R value and the total loss at normal frequency, shall be taken as the stray load-loss. This method is not accurate with induction motors in which the slots are entirely closed. In such machines these losses may be greater.

460 **Polyphase Induction-Motor Rotor I^2R Loss.** This should be determined from the slip, whenever the latter is accurately determinable, using the following equation:

$$\text{Rotor } I^2R \text{ loss} = \frac{\text{Output} \times \text{slip}}{1 - \text{slip}}$$

In large slip-ring motors, in which the slip cannot be directly measured by loading, the rotor I^2R loss shall be determined by direct resistance measurement; the rotor full-load current to be calculated by the following equation:

$$\text{Current per ring} = \frac{\text{watts output}}{\text{rotor voltage at stand-still} \times \sqrt{3} \times K}$$

This equation applies to three-phase rotors. For rotors wound for two phase, use 2 instead of the $\sqrt{3}$. K may be taken as 0.05 for motors of 150 kw. or larger. The factor K usually decreases as the size of motor is reduced, but no specific value can be stated for smaller sizes.

DETERMINATION OR APPROXIMATION OF LOSSES IN TRANSFORMERS

470 **No-Load Losses.** These shall be measured with open secondary circuit at the rated frequency, and with an applied primary voltage giving the rated secondary voltage plus the IR drop which occurs in the secondary under rated-load conditions. These no-load losses include core losses, consisting of hysteresis and eddy-current losses in the core, as well as dielectric loss in insulation due to electrostatic flux, which latter loss increases rapidly with temperature, and the test should therefore preferably be made at the reference temperature of 75°C.

471 **Stray Load-Losses.** These shall be measured by applying a primary voltage sufficient to produce rated-load current in the primary and secondary windings, the latter being short circuited. The stray load-losses will then be equal to the input decreased by the measured I^2R losses in both windings, as computed from resistance measurements at actual temperature, and the rated current. It is ordinarily immaterial whether the high-voltage or low-voltage winding is used as the primary winding in this test.

TESTS OF DIELECTRIC STRENGTH OF MACHINERY

480 **Basis for Determining Test Voltages.** The test voltage which shall be applied to determine the suitability of insulation for commercial operation is dependent upon the kind and size of the machinery, and its normal operating voltage, upon the nature of the service in which it is to be used, and upon the severity of the mechanical and electrical stresses to which it may be subjected. The voltages and other conditions of test which are recommended, have been determined as reasonable and proper for the great majority of cases, and are proposed for general adoption, except when specific reasons make a modification desirable.

481 **Condition of Machinery to be Tested.** Commercial tests shall, in general, be made with the completely assembled machinery and not with individual parts. The machinery shall be in good condition, and high-voltage tests, unless otherwise specified, shall be applied before the machine is put into commercial service, and shall

not be applied when the insulation resistance is low owing to dirt or moisture. High-voltage tests shall be made at the temperature assumed under normal operation or at the temperature attained under the conditions of commercial testing. High-voltage tests to determine whether specifications are fulfilled, are admissible on new machines only. Unless otherwise agreed upon, high-voltage tests of a machine shall be understood as being made at the factory.

482 **Points of Application of Voltage.** The test voltage shall be successively applied between each electric circuit and all other electric circuits and metal parts grounded.

483 **Interconnected Polyphase Windings** are considered as one circuit. All windings of a machine except that under test, shall be connected to ground.

484 **Frequency, Wave Form and Test Voltage.** The frequency of the testing circuit shall not be less than the rated frequency of the apparatus tested. A sine-wave form is recommended. See **§405.** The test shall be made with alternating voltage having a crest value equal to $\sqrt{2}$ times the specified test voltage. In d.c. machines, and in the general commercial application of a.c. machines, the testing frequency of 60 cycles per second is recommended.

485 **Duration of Application of Test Voltage.** The testing voltage for all classes of apparatus shall be applied continuously for a period of 60 seconds.

486 **Apparatus for Use on Single-Phase, 3-Phase-Delta or 3-Phase-Star Circuits.** Apparatus, such as transformers, which may be used in star connection on three-phase circuits, shall have the delta voltage of the circuits on which they may be used indicated on the rating plate and the test shall be based on such delta voltage.

VALUES OF A-C. TEST VOLTAGES

500 **The Standard Test for All Classes of Apparatus, Except as Otherwise Specified, Shall be Twice the Normal Voltage of the Circuit to Which the Apparatus is Connected, Plus 1000 Volts.**

501 *Exception*—**Alternating-Current Apparatus connected to Permanently Grounded Single-Phase Systems, for use on Permanently Grounded Circuits of more than 300 Volts,** shall be tested with 2.73 times the voltage of the circuit to ground + 1000 volts. This does not refer to three-phase apparatus with grounded star neutral.

502 *Exception*—**Distributing Transformers.** Transformers for primary pressures from 550 to 5000 volts, the secondaries of which are directly connected to consumers' circuits and commonly known as distributing transformers, shall be tested with 10,000 volts from primary to core and secondary combined. The secondary windings shall be tested with twice their normal voltage plus 1000 volts.

503 *Exception*—**Auto-Transformers** used for starting purposes, shall be tested with the same voltage as the test voltage of the apparatus to which they are connected.

504 *Exception*—**Household Devices.** Apparatus taking not over 660 watts† and intended solely for operation on supply circuits not exceeding 250 volts, shall be tested with 900 volts, except in the case of heating devices which shall be tested with 500 volts at operating temperature.

505 *Exception*—**Apparatus for use on Circuits of 25 Volts or Lower,** such as bell-ringing apparatus,* electrical apparatus used in automobiles, apparatus used on low-voltage battery circuits, etc., shall be tested with 500 volts.

506 *Exception*—**Field Windings of Alternating-Current Generators** shall be tested with 10 times the exciter voltage, but in no case with less than 1500 volts nor more than 3500 volts.

507 *Exception*—**Field Windings‡ of Synchronous Machines,** including motors and converters which are to be started from alternating-current circuits, shall be tested as follows:

a. When machines are started with fields short-circuited they shall be tested as specified in §506.

b. When machines are started with fields open-circuited and sectionalized while starting, they shall be tested with 5000 volts.

c. When machines are started with fields open-circuited and connected all series while starting, they shall be tested with 5000 volts for less than 250-volt excitation and 8000 volts for excitation of 250 volts to 750 volts.

508 *Exception.* **Phase-Wound Rotors of Induction Motors.** The secondary windings of wound rotors of induction motors shall be tested with twice their normal induced voltage, plus 1000 volts.

When induction motors with phase-wound rotors are reversed, while running at approximately normal speed, by reversing the primary connections, the test shall be four times the normal induced voltage, plus 1000 volts.

509 *Exception*—**Switches and Circuit Control Apparatus above 600 volts,** shall be tested with 2¼ times rated voltage, plus 2000 volts. See §720 to 741.

510 *Exception*—**Assembled Apparatus.** Where a number of pieces of apparatus are assembled together and tested as an electrical unit, they shall be tested with 15 per cent lower voltage than the lowest required on any of the individual pieces of apparatus.

511 **Testing Transformers by Induced Voltage.** Under certain conditions it is permissible to test transformers by inducing the required voltage in their windings, in place of using a separate testing transformer. By "required voltage", is meant a voltage such that the line end of the windings shall receive a test to ground equal to that required by the general rules.

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†The present National Electric Code power limit for a single outlet.

*This rule does not include bell-ringing transformers of ratio 125 to 6 volts. See National Electric Code.

‡Series field coils should be regarded as part of the armature circuit and tested as such.

512 **Transformers with Graded Insulation** shall be so marked. They shall be tested by inducing the required test-voltage in the transformer and connecting the successive line leads to ground.

Transformer windings permanently grounded within the transformer shall be tested by inducing the required test voltage in such windings. (See §500).

MEASUREMENT OF VOLTAGE IN DIELECTRIC TESTS OF MACHINERY

530 **Use of Voltmeters and Spark-Gaps in Insulation Tests.** When making insulation tests on electrical machinery, every precaution must be taken against the occurrence of any spark-gap discharges in the circuits from which the machinery is being tested. A non-inductive resistance of about one ohm per volt shall be inserted in series with one terminal of the spark gap. If the test is made with one electrode grounded, this resistance shall be inserted directly in series with the non-grounded electrode. If neither terminal is grounded, one-half shall be inserted directly in series with each electrode. In any case this resistance shall be as near the measuring gap as possible and not in series with the tested apparatus. The resistance will damp high-frequency oscillations at the time of breakdown and limit the current which will flow. A water tube is the most reliable form of resistor. Carbon resistors should not be used because their resistance may become very low at high voltages.

531 For Machinery of Low Capacitance. When the machinery under test does not require sufficient charging current to distort the high-voltage wave shape, or change the ratio of transformation, the spark gap should be set for the required test voltage and the testing apparatus adjusted to give a voltage at which this spark gap just breaks down. This adjustment should be made with the apparatus under test disconnected. The apparatus should then be connected, and with the spark gap about 20 per cent longer, the testing apparatus is again adjusted to give the voltage of the former breakdown, which is the assumed voltage of test. This voltage is to be maintained for the required interval.

532 For Machinery of High Capacitance. When the charging current of the machinery under test may appreciably distort the voltage wave or change the effective ratio of the testing transformer, the first adjustment of voltage with the gap set for the test voltage should be made with the apparatus under test connected to the circuit and in parallel with the spark gap.

When making arc-over tests of large insulators, leads, etc. partial arc-over of the tested apparatus may produce oscillations which will cause the measuring gap to discharge prematurely. The measured voltage will then appear too high. In such tests the "equivalent ratio" of the testing transformer should be measured by gap to within 20% of the arc-over voltage of the tested apparatus with the tested apparatus in circuit. The measuring gap should then be greatly lengthened out and the voltage increased until the tested apparatus arcs over. This arc-over voltage should then be determined by multiplying the voltmeter reading by the equivalent ratio found above. Direct measurement of the spark-over voltage over one gap by another gap should always be avoided.

533 **Measurements with Voltmeter.** In measuring the voltage with a voltmeter, the instrument should preferably derive its voltage from the high-tension circuit, either directly, or by means of a voltmeter coil placed in the testing transformer, or through an auxiliary *ratio transformer.* It is permissible to measure the voltage at other places, such as the transformer primary provided corrections can be made for the variations in ratio caused by the charging current of the machinery under test, or provided there is no material variation of this ratio. In any case, when the capacitance of the apparatus to be tested is such as to cause wave distortion, the testing voltage must be checked by a spark gap as set forth in §538, or by a crest voltage meter. If the crest-voltage meter is calibrated in crest volts, its readings must be reduced to the corresponding r. m. s. sinusoidal value by dividing with $\sqrt{2}$.

534 **Measurements with Spark Gaps.** If proper precautions are observed, spark gaps may be used to advantage in checking the calibration of voltmeters when set up for the purposes of high-voltage tests of the insulation of machinery.

535 **Ranges of Voltages.** For the calibrating purposes set forth in §534 the sphere-gap shall be used for voltages above 50 kv., and is to be preferred down to 30 kv. The needle spark-gap may, however, be used for voltages from 10 to 50 kv.

536 **The Needle Spark Gap.** The needle spark gap shall consist of new sewing needles, supported axially at the ends of linear conductors which are at least twice the length of the gap. There must be a clear space around the gap for a radius of at least twice the gap length.

537 The sparking distances in air between No. 00 sewing needle points for various root-mean-square sinusoidal voltages are as follows:

TABLE VII.

Needle-Gap Spark-Over Voltages

(At 25°C and 760 mm. barometer).

R M S Kilovolts	Millimeters	R.M.S. Kilovolts	Millimeters
10	11.9	35	51
15	18.4	40	62
20	25.4	45	75
25	33	50	90
30	41		

The above values refer to a relative humidity of 80 per cent. Variations from this humidity may involve appreciable variations in the sparking distance.

538 **The Sphere Spark-Gap.** The standard sphere spark-gap shall consist of two suitably mounted metal spheres. When used as specified below, the accuracy obtainable should be approximately 2 per cent.

No extraneous body, or external part of the circuit, shall be nearer the gap than twice the diameter of the spheres. By the "gap" is meant the shortest path between the two spheres.

The shanks should not be greater in diameter than 1/5th the sphere diameter. Metal collars, etc., through which the shanks extend, should be as small as practicable and should not, during any measurement, come closer to the sphere than the maximum gap length used in that measurement.

The sphere diameter should not vary more than 0.1 per cent and the curvature, measured by a spherometer, should not vary more than 1 per cent from that of a true sphere of the required diameter.

539 **In using the spherometer** to measure the curvature, the distance between the points of contact of the spherometer feet should be within the following limits:

TABLE VIII

Spherometer Specifications

Diameter of Sphere in m.m.	Distance between contact points in mm.	
	Maximum	Minimum
62.5	35	25
125	45	35
250	65	45
500	100	65

539A **In using Sphere Gaps** constructed as above, it is assumed that the apparatus will be set up for use in a space comparatively free from external dielectric fields. Care should be taken that conducting bodies forming part of the circuit, or at circuit potential, are not so located with reference to the gap that their dielectric fields are superposed on the gap; *e.g.*, the protecting resistance should not be arranged so as to present large masses or surfaces near the gap, even at a distance of two sphere diameters.

In case the sphere is grounded, the spark point of the grounded sphere should be approximately five diameters above the floor or ground.

540 **The sparking distances between different spheres** for various r.m.s sinusoidal voltages shall be assumed to be as follows:

TABLE IX.

Sphere-Gap Spark-Over Voltages

(At 25°C and 760 mm. barometric pressure)

Kilo-volts	Sparking Distance in Millimeters.							
	62.5 mm. spheres		125 mm. spheres		250 mm. spheres		500 mm. spheres	
	One sphere grounded	Both spheres insulated	One sphere grounded	Both spheres insulated	One sphere grounded	Both spheres insulated	One sphere grounded	Both spheres insulated
10	4.2	4.2	..	..	..	..	..	..
20	8.6	8.6	..	..	..	..	..	..
30	13.5	13.5	14.1	14.1	..	..	..	..
40	19.2	19.2	19.1	19.1	..	..	..	..
50	25.5	25.0	24.4	24.4	..	..	..	..
60	34.5	32.0	30.	30.	29	29	..	..
70	46.0	39.5	36	36	35	35	..	..
80	62.0	49.0	42	42	41	41	41	41
90		60.5	49	49	46	45	46	45
100			56	55	52	51	52	51
120			70.7	71	64	63	63	62
140			108	88	78	77	74	73
160			150	110	92	90	85	83
180				138	109	106	97	95
200					128	123	108	106
220					150	141	120	117
240					177	160	133	130
260					210	180	148	144
280					250	203	163	158
300						231	177	171
320						265	194	187
340							214	204
360							234	221
380							255	230
400							270	257

The sphere gap is more sensitive than the needle gap to momentary rises of voltage and the voltage required to spark over the gap should be obtained by slowly closing the gap under constant voltage, or by slowly raising the voltage with a fixed setting of the gap. Open arcs should not be permitted in proximity to the gap during its operation, as they may affect its calibration.

AIR-DENSITY CORRECTION-FACTORS FOR SPHERE GAPS

541 **The Spark-Over Voltage,** for a given gap, decreases with decreasing barometric pressure and increasing temperature. This correction may be considerable at high altitudes.

The spacing at which it is necessary to set a gap to spark over at some required voltage, is found as follows: Divide the required voltage by the correction factor given below in Table X. A new voltage is thus obtained. The spacing on the standard curves obtained from Table IX, corresponding to this new voltage, is the required spacing.

The voltage at which a given gap sparks over is found by taking the voltage corresponding to the spacing from the standard curves of Table IX, and multiplying by the correction factor.

When the variation from sea level is not great, the relative air density may be used as the correction factor; when the variation is great, or greater accuracy is desired, the correction factor corresponding to the relative air density should be taken from Table X below, in which

$$\text{Relative air density} = \frac{0.392\, b}{273 + t}$$

b = barometric pressure in mm.
t = temperature in deg. C.

Corrected curves may be plotted for any given altitude, if desired.

Values of relative air density and corresponding values of the correction factor are tabulated below. It will be seen that for values above .9, the correction factor does not differ greatly from the relative air density.

TABLE X.

Air-Density Correction Factors for Sphere Gaps

Relative air density	Diameter of standard spheres in mm.			
	62.5	125	250	500
0.50	0.547	0.535	0.527	0.519
0.55	0.594	0.583	0.575	0.567
0.60	0.640	0.630	0.623	0.615
0.65	0.686	0.677	0.670	0.663
0.70	0.732	0.724	0.718	0.711
0.75	0.777	0.771	0.766	0.759
0.80	0.821	0.816	0.812	0.807
0.85	0.866	0.862	0.859	0.855
0.90	0.910	0.908	0.906	0.904
0.95	0.956	0.955	0.954	0.952
1.00	1.000	1.000	1.000	1.000
1.05	1.044	1.045	1.046	1.048
1.10	1.090	1.092	1.094	1.096

INSULATION RESISTANCE OF MACHINERY

550 **The insulation resistance of a machine** at its operating temperature shall be not less than that given by the following formula:

$$\text{Insulation Resistance in megohms} = \frac{\text{voltage at terminals}}{\text{rated capacity in kv-a.} + 1000}$$

The formula only applies to dry apparatus. Such high values are not attainable in oil-immersed apparatus.

Insulation resistance tests shall, if possible, be made at a d.c. pressure of 500 volts. Since the insulation resistance varies with the pressure, it is necessary that, if a pressure other than 500 volts is to be employed in any case, this other pressure shall be clearly specified.

The order of magnitude of the values obtained by this rule is shown in the following table:

TABLE XI.

Insulation Resistance of Machinery

Rated Voltage of machine	Megohms		
	100 kv-a.	1000 kv-a.	10,000 kv-a.
100	0.091	0.05	—
1,000	0.91	0.50	0.091
10,000	9.1	5.0	0.91
100,000	—	50	9.1

551 It should be noted that the insulation resistance of machinery is of doubtful significance by comparison with the dielectric strength. The insulation resistance is subject to wide variation with temperature, humidity and cleanliness of the parts. When the insulation resistance falls below that corresponding to the above rule, it can, in most cases of good design and where no defect exists, be brought up to the required standard by cleaning and drying out the machine. The insulation-resistance test may therefore afford a useful indication as to whether the machine is in suitable condition for the application of the dielectric test.

REGULATION

DEFINITIONS

560 **Regulation.** The regulation of a machine in regard to some characteristic quantity (such as terminal voltage or speed) is the change in that quantity occurring between any two loads. Unless otherwise specified, the two loads considered shall be zero load and rated load, and at the temperature attained under normal operation. The regulation may be expressed by stating the numerical values of the quantity at the two loads, or it may be ex-

pressed by the "percentage regulation", which is the percentage ratio of the change in the quantity occurring between the two loads, to the value of the quantity at either one or the other load, taken as the normal value. It is assumed that all parts of the machine affecting the regulation maintain constant temperature between the two loads, and where the influence of temperature is of consequence, a reference temperature of 75°C shall be considered as standard. If change of temperature should occur during the tests, the results shall be corrected to the reference temperature of 75°C.

The normal value may be either the no-load value, as the no-load speed of induction motors; or it may be the rated-load value, as in the voltage of a.c. generators.

It is usual to state the regulation of d-c. generators by giving the numerical values of the voltage at no load and rated load, and in some cases it is advisable to state regulation at intermediate loads.

501 The **Regulation of d-c. Generators** refers to changes in voltage corresponding to gradual changes in load and does not relate to the comparatively large momentary fluctuations in voltage that frequently accompany instantaneous changes in load.

In determining the regulation of a compound-wound d-c. generator, two tests shall be made, one bringing the load down and the other bringing the load up, between no-load and rated load. These may differ somewhat, owing to residual magnetism. The mean of the two results shall be used.

502 In **constant-potential a-c. generators,** the regulation is the rise in voltage (when the specified load at specified power factor is thrown off) expressed in per cent of normal rated-load voltage.

503 In **constant-current machines,** the regulation is the ratio of the maximum difference of current from the rated-load value (occurring in the range from rated-load to short-circuit, or minimum limit of operation), to the rated-load current.

504 In **constant-speed direct-current motors,** and induction motors, the regulation is the ratio of the difference between full-load and no-load speeds to the no-load speed.

505 In **constant-potential transformers,** the regulation is the difference between the no-load and rated-load values of the secondary terminal voltage at the specified power factor (with constant primary impressed terminal voltage) expressed in per cent of the rated-load secondary voltage, the primary voltage being adjusted to such a value that the apparatus delivers rated output at rated secondary voltage.

506 In **convertors, dynamotors, motor-generators and frequency converters,** the regulation is the change in the terminal voltage of the output side between the two specified loads. This may be expressed by giving the numerical values, or as the percentage of the terminal voltage at rated load.

507 In **transmission lines, feeders etc.,** the regulation is the change in the voltage at the receiving end between rated non-inductive load and no load, with constant impressed voltage upon the sending

end. The percentage regulation is the percentage change in voltage to the normal rated voltage at the receiving end.

568 In **steam engines, steam turbines and internal combustion engines,** the percentage speed regulation is usually expressed as the percentage ratio of the maximum variation of speed, to the rated-load speed in passing slowly from rated load to no load (with constant conditions at the supply.)

569 If the test is made by passing suddenly from rated load to no load, the immediate percentage speed regulation so derived shall be termed the **fluctuation.**

570 In a **hydraulic turbine,** or other water motor, the percentage speed regulation is expressed as the percentage ratio of the maximum variation in speed in passing slowly from rated load to no load (at constant head of water), to the rated-load speed.

571 In a **generator unit,** consisting of a generator combined with a prime mover, the speed or voltage regulation should be determined at constant conditions of the prime mover; *i.e.* constant steam-pressure, head, etc. It includes the inherent speed variations of the prime mover. For this reason, the regulation of a generator unit is to be distinguished from the regulation of either the prime mover, or of the generator combined with it, when taken separately.

CONDITIONS FOR TESTS OF REGULATION

580 **Speed and Frequency.** The regulation of generators is to be determined at constant speed, and of alternating-current apparatus at constant frequency.

581 **Power Factor.** In apparatus generating, transforming or transmitting alternating currents, the power factor of the load to which the regulation refers should be specified. Unless otherwise specified, it shall be understood as referring to non-inductive load, that is to a load in which the current is in phase with the *e.m f.* at the output side of the apparatus.

582 **Wave Form.** In the regulation of alternating-current machinery receiving electric power, a sine wave of voltage is assumed, except where expressly specified otherwise. See **§405.**

583 **Excitation.** In commutating machines, rectifying machines, and synchronous machines, such as direct-current generators and motors, as well as in alternating-current generators, the regulation is to be determined under such conditions as to maintain the field adjustment constant at that which gives rated-load voltage at rated-load current, as follows:

(1) In the case of separately-excited field magnets—constant excitation.

(2) In the case of shunt machines, constant resistance in the shunt-field circuit.

(3) In the case of series or compound machines, constant resistance shunting the series-field windings.

584 **Tests and Computation of Regulation of A-C. Generators.**

Any one of the three following methods may be used. They are given in the order of preference.

Method a.

The regulation can be measured directly, by loading the generator at the specified load and power factor, then reducing the load to zero, and measuring the terminal voltage, with speed and excitation adjusted to the same values as before the change. This method is not generally applicable for shop tests, particularly on large generators, and it becomes necessary to determine the regulation from such other tests as can be readily made.

585 **Method b.**

This consists in computing the regulation from experimental data of the open-circuit saturation curve and the zero-power-factor saturation curve. The latter curve, or one approximating very closely to it, can be obtained by running the generator with over excitation on a load of idle-running under-excited synchronous motors. The power factor under these conditions is very low and the load saturation curve approximates very closely the zero power factor saturation curve. From this curve and the open circuit curve, points for the load saturation curve, for any power factor, can be obtained by means of vector diagrams.

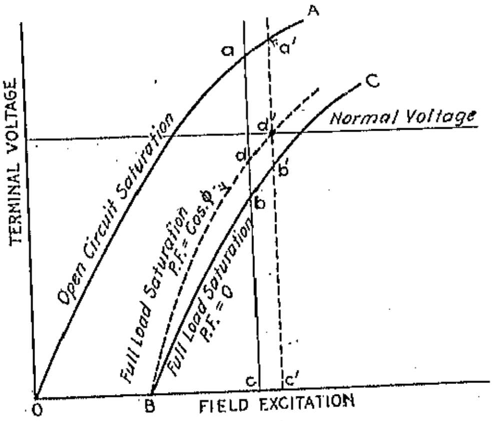

FIG. 1

To apply Method b, it is necessary to obtain from test, the open-circuit saturation curve OA, Fig. 1, and the saturation curve BC at zero power factor and rated-load current. At any given excitation Oc, the voltage that would be induced on open circuit is ac, the terminal voltage at zero power factor is bc, and the apparent internal drop is ab. The terminal voltage dc at any other power factor can then be found by drawing an e.m.f. diagram* as in Fig. 2, where ϕ is an angle such that *cos* ϕ is the power factor of the load, *b e* the resistance drop (IR) in the stator winding, *ba* the total internal drop, and *ac* the total induced voltage; *ba* and *ac* being laid off to correspond with the values obtained from Fig. 1. The terminal voltage at power factor *cos* ϕ, is then *cb* of Fig. 2, which, laid off in Fig. 1, gives point *d*. By finding a number of such points, the curve *Bdd'* for power factor *cos* ϕ is obtained and the regulation at this power factor (expressed in per cent) is $\frac{100 \times a'd'}{d'\,c'}$, since *a' d'* is the rise in voltage when the load at power factor *cos* ϕ is thrown off at normal voltage *c' d'*.

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*Method b, for deducing the load saturation curve, at any assigned power factor, from no-load and zero-power-factor saturation curves obtained by test, must be regarded as empirical. Its value depends upon the fact that experience has demonstrated the reasonable correctness of the results obtained by it.

Generally, the ohmic drop can be neglected, as it has very little influence on the regulation, except in very low-speed machines where the armature resistance is relatively high, or in some cases where regulation at unity power factor is being estimated. For low power factors, its effect is negligible in practically all cases. If resistance is neglected, the simpler e.m.f. diagram, Fig. 3, may be used to obtain points on the load saturation curve for the power factor under consideration.

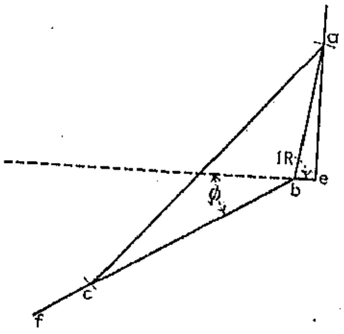


FIG. 2

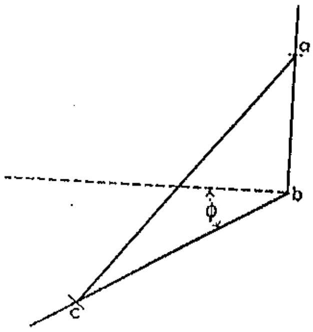


FIG. 3

586 **Method c.**

Where it is not possible to obtain by test a zero-power-factor saturation curve as in Method b, this curve can be estimated closely from open-circuit and short-circuit curves, by reference to tests at zero power factor on other machines of similar magnetic circuit. Having obtained the estimated zero-power-factor curve, the load saturation for any other power factor is obtained as in method b.

Thus Method c is the same as Method b; except that the zero-power-factor curve must be estimated. This may be done as follows. In Fig. 4, *OA* is the open-circuit saturation curve and *OE* the short-circuit line as shown by test. The zero-power-factor curve corresponding to any given current *BF* will start from point *B*, and for machines designed with low saturation and low reactance, will follow parallel to *OA*, as shown by the dotted curve *BD*, which is *OA* shifted horizontally parallel to itself by the distance *OB*. In high-speed machines, or in others having low reactance and a low degree of saturation in the magnetic circuit, the zero-power-factor curve will lie quite close to *BD*, particularly in those parts that are used for determining the regulation. This is the case with many turbo-generators and high-speed water-wheel generators. In many cases, however, the zero-power-factor curve will deviate from *BD*, as shown by *BC*, and the deviation will be most pronounced in machines of high reactance, high saturation, and large magnetic leakage. The position of the actual curve *BC* with relation to *BD*, can be approximated with sufficient exactness by investigating the corresponding relation as obtained by test at zero power factor on machines of similar characteristics and magnetic circuit. Or curve *BC* can be calculated by methods based on the results of tests at zero power factor. After *BC* has been obtained, the saturation curve and regulation for any other power factor can be derived as in Method (b).

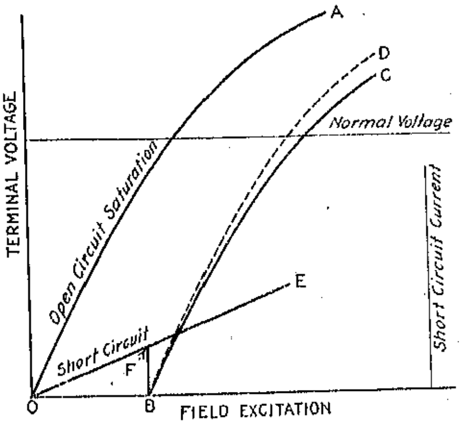


FIG. 4

587 Tests and Computation of Regulation for Constant-Potential Transformers.

The regulation can be determined by loading the transformer and measuring the change in voltage with change in load, at the specified power factor. This method is not generally applicable for shop tests, particularly on large transformers.

The regulation for any specified load and power factor can be computed from the measured impedance watts and impedance volts, as follows:

Let:

P = impedance watts, as measured in the short-circuit test at 75°C.

E_s = impedance volts, as measured in the short-circuit test.

IX = Reactance Drop in Volts.

I = Rated Primary Current.

E = Rated Primary Voltage.

q_r = percent drop in phase with current.
q_x = percent drop in quadrature with current.

$$IX = \sqrt{E_z^2 - \left(\frac{P}{I}\right)^2}$$

$$q_r = 100\frac{P}{EI}$$

$$q_x = 100\frac{IX}{E}$$

588 Then—

1. For **unity power factor**, we have approximately:-

$$\text{Per cent regulation} = q_r + \frac{q^2_x}{200}$$

589 2. For **inductive loads** of power-factor m and reactive-factor n,

$$\text{Per cent regulation} = mq_r + nq_x + \frac{(mq_x - nq_r)^2}{200}$$

TRANSFORMER CONNECTIONS

SINGLE-PHASE TRANSFORMERS

600 **Marking of Leads.**

The leads of single-phase transformers shall be distinguished from each other by marking the high-voltage leads with the letters *A* and *B*, and the low-voltage leads with the letters *X* and *Y*. They shall be so marked that the potential difference between *A* and *B* shall have the same direction at any instant as the potential difference between *X* and *Y*.

In accordance with the above rule, the terminals of single-phase transformers shall be marked as follows:

601 (1) High- and Low-Voltage Windings in Phase:

A ——— *B*
X ——— *Y*

602 (2) High- and Low-Voltage Windings 180 deg. Apart in Phase:

A ——— *B*
Y ——— *X*

603 **To operate transformers thus marked in parrallel,**it is only necessary to connect similarly marked terminals together, (provided that the reactances and resistances of the transformers are such as to permit of parallel operation).

604 **Single-Phase Transformers with More Than Two Windings.**

Transformers possessing three or more windings (each being provided with separate out-going leads), shall have the leads connected to two of their windings, lettered in accordance with the preceding paragraph. The remaining leads shall be distinguished from the others by a subscript. For example, transformers possessing four secondary leads connected to two distinct similar windings for multiple-series operation, shall be lettered as follows:

$$\begin{array}{c} A \text{———} B \\ \left\{\begin{array}{c} X \text{———} Y \\ X_1 \text{———} Y_1 \end{array}\right\} \end{array}$$

This indicates that the low-voltage winding consists of two disconnected parts, one part having terminals XY and the other part having terminals X_1Y_1. For multiple connection, X and X_1 are connected together and Y and Y_1 are connected together. For series connection, Y is connected to X_1.

605 **Neutral Lead**

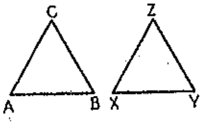
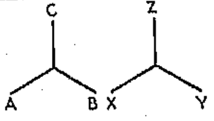
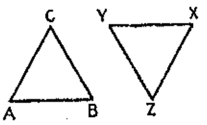
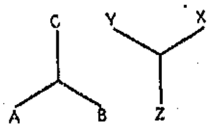
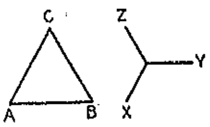
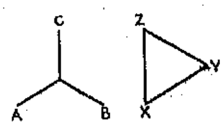
An out-going 50 per cent. (neutral) tap lead should be lettered N.

606 **Internal Connections**

The manufacturer shall furnish a complete diagrammatic sketch of internal connections, and all taps and terminals of the transformer shall be marked to correspond with numbers or letters in the sketch.

THREE-PHASE TRANSFORMERS

607 Three-phase transformers ordinarily have three or four leads for high-voltage, and three or four leads for low-voltage windings. To distinguish the various leads from each other, and also to distinguish between the various phase relations obtainable, the three high-voltage leads should be lettered A B C and the three low-voltage leads X Y Z. In addition, it should be distinctly stated in which of the three groups given in the following diagram the transformer belongs.

	A	B
GROUP I *Angular Displacement* *0°*		
GROUP II *Angular Displacement* *180°*		
GROUP III *Angular Displacement* *30°*		

608 The rules given above for **single-phase transformers in regard to the neutral tap,** (See **§605**) and also in regard to internal connections, (See **§600** to **§604**) are applicable to three-phase transformers.

609 **Angular Displacement.**

The angular displacement between high- and low-voltage windings, is the angle in the diagram in **§607**, between the lines passing from the neutral point through A and X respectively. Thus, in Group 1, the angular displacement is zero degrees. In Group 2, the angular displacement is 180°, and in Group 3 the angular displacement is 30°.

610 **Parallel Operation of Three-Phase Transformers.**

Three-phase transformers, lettered in accordance with the above rules, will operate correctly in parallel, if at their rated loads, their percentage resistance drops are equal, and their percentage reactance drops, are equal. It is furthermore necessary that the angular displacements between high-voltage and low-voltage windings shall be equal, *i.e.* that the transformers shall belong to the same group in the diagram in **§607**. It is then only necessary to connect together similarly marked leads.

INFORMATION ON THE RATING PLATE OF A MACHINE

620 It is recommended that the rating plate of machines which comply with the Institute rules shall carry a distinctive special sign, such as "A.I.E.E. 1915 Rating" or "A15" Rating.

621 The absence of any statement to the contrary on the rating plate of a machine implies that it is intended for continuous service and for the standard altitude and ambient temperature of reference. See **§§287, 305, 308** and **309.**

622 The rating plate of a machine intended to work under various kinds of rating must carry the necessary information in regard to those kinds of ratings.

623 The rating plate, in addition to the name of the manufacturer and the serial number, should give the following information.*

624 **Generator, Direct-Current.**
Shunt, series, or compound.
Output, in kw., with statement as to the kind of rating.
Terminal pressure, in volts.
Current, in amperes.
Speed, in revolutions per minute.

625 **Motor, Direct-Current.**
Shunt, series, or compound.
Output, in kw., with statement as to the kind of rating.
Terminal pressure, in volts.
Current, approximate, in amperes.
Speed, in revolutions per minute.

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*Information, for which space on the rating plate cannot be provided, shall be furnished on a supplementary rating certificate.

626 **Transformer.**

Frequency, in cycles per second.

Number of phases.

Output at the secondary terminals in kv-a., with statement as to the kind of rating.

High pressure, in volts.

Low pressure, in volts. See §§202, 203 and 204.

Lead markings and diagram of internal connections, as set forth in §600 to 609.

627 **Alternator.**

Frequency, in cycles per second.

Number of poles.

Number of phases.

Output, in kv-a., with statement as to the kind of rating.

Power-factor corresponding to rated output.

Pressure between terminals, in volts, corresponding to the rated output.

Current in amperes.

Speed in revolutions per minute.

628 **Synchronous Motor.**

Frequency, in cycles per second.

Number of poles.

Number of phases.

Mechanical output, in kw., with statement as to the kind of rating.

Pressure between terminals, in volts, corresponding to the rated output.

Current in amperes.

If the motor is intended to work with a power factor different from unity, the necessary information shall be given.

Speed, in revolutions per minute.

629 **Synchronous Converter.**

Frequency in cycles per second.

Number of poles.

Number of phases.

Output at commutator in kilowatts, with statement as to kind of rating.

D-c. terminal pressure in volts.

Current from commutator in amperes.

Speed in revolutions per minute.

630 **Induction Motor.**

Frequency, in cycles per second.

Number of poles.

Number of phases.

Mechanical output, in kw., with statement as to the kind of rating.

Pressure between terminals, in volts.

Current, in amperes.

Speed, in revolutions per minute, at rated output.

STANDARDS FOR WIRES AND CABLES

TERMINOLOGY*

635 **Wire.**—A slender rod or filament of drawn metal.

The definition restricts the term to what would ordinarily be understood by the term "solid wire." In the definition, the word "slender" is used in the sense that the length is great in comparison with the diameter. If a wire is covered with insulation, it is properly called an insulated wire; while primarily the term "wire" refers to the metal, nevertheless when the context shows that the wire is insulated, the term "wire" will be understood to include the insulation.

636 **Conductor.**—A wire or combination of wires not insulated from one another, suitable for carrying a single electric current.

The term "conductor" is not to include a combination of conductors insulated from one another, which would be suitable for carrying several different electric currents.

Rolled conductors (such as busbars) are, of course, conductors, but are not considered under the terminology here given.

637 **Stranded Conductor.**—A conductor composed of a group of wires, or of any combination of groups of wires.

The wires in a stranded conductor are usually twisted or braided together.

638 **Cable.**—(1) A stranded conductor (single-conductor cable); or (2) a combination of conductors insulated from one another (multiple-conductor cable).

The component conductors of the second kind of cable may be either solid or stranded, and this kind of cable may or may not have a common insulating covering. The first kind of cable is a single conductor, while the second kind is a group of several conductors. The term "cable" is applied by some manufacturers to a solid wire heavily insulated and lead-covered; this usage arises from the manner of the insulation, but such a conductor is not included under this definition of "cable." The term "cable" is a general one, and, in practise, it is usually applied only to the larger sizes. A small cable is called a "stranded wire" or a "cord," both of which are defined below. Cables may be bare or insulated, and the latter may be armored with lead, or with steel wires or bands.

639 **Strand.**—One of the wires, or groups of wires, of any stranded conductor.

640 **Stranded Wire.**—A group of small wires, used as a single wire.

A wire has been defined as a slender rod or filament of drawn metal. If such a filament is subdivided into several smaller filaments or strands, and is used as a single wire, it is called a "stranded wire." There is no sharp dividing line of size between a "stranded wire" and a "cable." If used as a wire, for example in winding inductance coils or magnets, it is called a stranded wire and not a cable. If it is substantially insulated, it is called a "cord," defined below.

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*From Circular No. 37 of the Bureau of Standards.

641 **Cord.**—A small and very flexible cable, substantially insulated to withstand wear.

There is no sharp dividing line in respect to size between a "cord" and a "cable," and likewise no sharp dividing line in respect to the character of insulation between a "cord" and a "stranded wire." Rubber is used as the insulating material for many classes of cords.

642 **Concentric Strand.**—A strand composed of a central core surrounded by one or more layers of helically-laid wires or groups of wires.

643 **Concentric-Lay Cable.**—A single-conductor cable composed of a central core surrounded by one or more layers of helically-laid wires.

644 **Rope-Lay Cable.**—A single-conductor cable composed of a central core surrounded by one or more layers of helically-laid groups of wires.

This kind of cable differs from the preceding in that the main strands are themselves stranded.

645 **N-Conductor Cable.**—A combination of N conductors insulated from one another.

It is not intended that the name as here given be actually used. One would instead speak of a "3-conductor cable," a "12-conductor cable" etc. In referring to the general case, one may speak of a "multiple-conductor cable" (as in definition §638 above.)

646 **N-Conductor Concentric Cable.**—A cable composed of an insulated central conducting core with (N — 1) tubular stranded conductors laid over it concentrically and separated by layers of insulation.

This kind of cable usually has only two or three conductors. Such cables are used for carrying alternating currents. The remark on the expression "N-conductor" given for the preceding definition applies here also.

647 **Duplex Cable.**—Two insulated single-conductor cables, twisted together.

They may or may not have a common insulating covering.

648 **Twin Cable.**—Two insulated single-conductor cables laid parallel, having a common covering.

649 **Triplex Cable.**—Three insulated single-conductor cables twisted together.

They may or may not have a common insulating covering.

650 **Twisted Pair.**—Two small insulated conductors, twisted together, without a common covering.

The two conductors of a "twisted pair" are usually substantially insulated, so that the combination is a special case of a "cord."

651 **Twin Wire.**—Two small insulated conductors laid parallel, having a common covering.

SPECIFICATION OF SIZES OF CONDUCTORS

652 The sizes of solid wires shall be stated by their diameter in mils, the American Wire Gage (Brown and Sharpe) sizes being taken as standard. The sizes of stranded conductors shall be stated by their cross-sectional area in circular mils. For brevity, in cases where the most

careful specification is not required, the sizes of solid wires may be stated by the gage number in the American Wire Gage, and the sizes of stranded conductors smaller than 250,000 circular mils (*i.e.*, No. 0000 A.W.G. or smaller) may likewise be stated by means of the gage number in the American Wire Gage of a solid wire having the same cross-sectional area. Futhermore, an exception is made in the case of "Flexible Stranded Conductors," for which see §655 below. In stating large cross-sections, it is sometimes convenient to use a circular inch (507 sq. mm.) instead of 1,000,000 circular mils.

STRANDING

653 Cables not requiring special flexibility shall be stranded in accordance with the following table.

TABLE XII

Standard Stranding of Concentric-Lay Cables

SIZE (See Note 1.)	Number of Wires. A Bare Cables for AERIAL USE*	B Weatherproof Cables for AERIAL USE*	C Insulated Cables
2.0 Cir. Inches	91	91	127
1.5	61	61	91
1.0	61	61	61
0.6	37	37	61
0.5	37	37	37
0.4	19	19	37
0000 A. W. G.	7	19	19
00	7	7	19
2	(See Note 2)	(See Note 2)	7
9	(See Note 2)	(See Note 2)	(See Note 2)

(1) For intermediate sizes, use stranding for next larger size.
(2) Solid Wire is recommended.

*Tentatively adopted pending ratification by other societies interested.

654 **Sectional Area of Cables.** The cross-sectional area of a cable shall be considered to be the sum of the cross-sectional areas of its component wires, when laid out straight and measured perpendicular to their axes.

655 **Flexible Stranding.** Conductors of special flexibility should ordinarily be made with wires of regular A.W.G. sizes, the number of wires and size being given. The approximate gage number or approximate circular mils of such flexible stranded conductors may be stated. The following stranding table is suggested.

TABLE XIII

Proposed Standard Stranding of Flexible Cables*

Nearest A. W. G. Size (See Note 1)	Circular Mils	Number of Wires	Size of Each Wire A. W. G.	Make-up (See Note 2)
–	1,102,941	427	16	61x7
–	874,496	427	17	"
–	693,448	427	18	"
–	549,976	427	19	"
–	436,394	427	20	"
–	345,913	427	21	"
–	274,390	427	22	"
–	264,608	259	20	37x7
0000	209,816	259	21	"
000	166,433	259	22	"
00	135,926	133	20	19x7
0	107,743	133	21	"
1	85,466	133	22	"
2	67,764	133	23	"
3	53,732	133	24	"
4	39,695	49	21	7x7
5	31,487	49	22	"
6	24,966	49	23	"
7	19,796	49	24	"
8	15,700	49	25	Optional (See Note 3)
9	12,451	49	26	"
10	9,854	49	27	"
11	7,830	49	28	"
12	6,208	49	29	"
Smaller		To equal required size	30	Bunched

Note 1. The A. W. G. sizes are approximated within 5 per cent.
Note 2. 61x7 signifies a rope-lay cable composed of 61 strands of 7 wires each.
Note 3. Rope-lay or bunched.

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* This table is offered for consideration but will not be recommended for final adoption until ratified by other societies interested. The addition of another Table giving a further degree of flexibility is under consideration. The stranding of No. 4 A. W. G. and smaller sizes, is particularly open for discussion.

656 **Correction for Lay.** The resistance and mass of a stranded conductor are greater than in a solid conductor of the same cross-sectional area, depending on the lay (*i.e.*, the pitch of the twist of the wires). Two per cent shall be taken as the standard increment of resistance and of mass. In cases where the lay is definitely known, the increment should be calculated and not assumed.

The direction of lay is the lateral direction in which the strands of a cable run over the top of the cable as they recede from an observer looking along the axis of the cable.

CONDUCTIVITY OF COPPER.

675 The following I. E. C. rules are adopted:*

The following shall be taken as normal values for standard annealed copper:

(1) At a temperature of 20°C., the resistance of a wire of standard annealed copper one meter in length and of a uniform section of 1 square millimeter is 1/58 ohm = 0.017241.... ohm.

(2) At a temperature of 20°C., the density of standard annealed copper is 8.89 grams per cubic centimeter.

(3) At a temperature of 20°C, the "constant mass" temperature coefficient of resistance of standard annealed copper, measured between two potential points rigidly fixed to the wire, is 0.00393 = 1/254.45.... per degree centigrade.

(4) As a consequence, it follows from (1) and (2) that, at a temperature of 20 °C. the resistance of a wire of standard annealed copper of uniform section, one meter in length and weighing one gram, is (1/58) × 8.89 = 0.15328...... ohm.†§

676 **Copper Wire Tables.** The copper-wire Tables published by the Bureau of Standards in Circular No. 31 are adopted. These Tables are based upon the I. E. C. rules stated in §675.

HEATING AND TEMPERATURE OF CABLES.

677 **Maximum Safe Limiting Temperatures.**

The maximum safe limiting temperature in degrees C. at the surface of the conductor in a cable shall be:—

For impregnated paper insulation	(85—E)
" varnished cambric	(75—E)
" rubber insulation	(60—0.25E)

where E represents the r.m.s. operating e.m.f. in kilovolts between conductors.

Thus, at a working pressure of 3.3 kv., the maximum safe limiting temperature at the surface of the conductor, or conductors, in a cable would be:—

For impregnated paper	81.7°C.
" varnished cambric	71.7°C.
" rubber insulation	59.2°C.

ELECTRICAL TESTS.

678 **Lengths Tested.** Electrical tests of insulation on wires and cables shall be made on the entire lengths to be shipped.

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*See I. E. C. Publication No. 28 "International Standard of Resistance for Copper" March 1914.

†Paragraphs (1) and (4) of §675 define what are sometimes called "volume resistivity," and "mass resistivity" respectively. This may be expressed in other units as follows:— volume resistivity = 1.7241 microhm-cm. (or microhms in a cm. cube) at 20 °C. = 0.67879 microhm-inch at 20 °C., and mass resistivity = 875.20 ohms (mile, pound) at 20 °C.

§For detailed specifications of commercial copper, see the "Standard Specifications" of the American Society for Testing Materials.

679 **Immersion in Water.** Electrical tests of insulated conductors not enclosed in a lead sheath, shall be made while immersed in water after an immersion of twelve (12) hours, if insulated with rubber compound, or if insulated with varnished cambric. It is not necessary to immerse in water insulated conductors enclosed in a lead sheath.

In multiple-conductor cables, without waterproof overall jacket of insulation, no immersion test should be made on finished cables, but only on the individual conductors before assembling.

680 **Dielectric-Strength Tests. Object of Tests.** Dielectric tests are intended to detect weak spots in the insulation and to determine whether the dielectric strength of the insulation is sufficient for enabling it to withstand the voltage to which it is likely to be subjected in service, with a suitable factor of assurance.

The initially-applied voltage must not be greater than the working voltage, and the rate of increase shall not be over 100 per cent in 10 seconds.

681 **Factor of Assurance.** The factor of assurance of wire or cable insulation shall be the ratio of the voltage at which it is tested to that at which it is used.

682 **Test Voltage.** The dielectric strength of wire and cable insulation shall be tested at the factory, by applying an alternating test voltage between the conductor and sheath or water.

683 **The Magnitude and Duration of the Test Voltage** should depend upon the dielectric strength and thickness of the insulation, the length and diameter of the wire or cable, and the assurance factor required, the latter in turn depending upon the importance of the service in which the wire or cable is employed.

684 **The following test voltages** shall apply unless a departure is considered necessary, in view of the above circumstances. Rubber covered wires or cable for voltages up to 7 kv. shall be tested in accordance with the National Electric Code. Standardization for higher voltages for rubber insulated cables is not considered possible at the present time.

Varnished cambric and impregnated paper insulated wires or cables shall be tested at the place of manufacture for five (5) minutes in accordance with the Table XIV below.

TABLE XIV

Recommended Test Kilovolts Corresponding to Operating Kilovolts

Operating kv.	Test kv.	Operating kv.	Test kv.
Below 0.5	2.5*	5	14
0.5	3	10	25
1	4	15	3[illegible]
2	6.5	20	44
3	9	25	53
4	11.5		

*The minimum thickness of insulation shall be 1/16″ (1-6 mm.)

Different engineers specify different thickness of insulation for the same working voltages. Therefore, at the present time the test kv. corresponding to working kv. given in Table XIV are based on the **minimum** thickness of insulation specified by engineers and operating companies.†

685 **The Frequency of the Test Voltage** shall not exceed 100 cycles per second, and should approximate as closely as possible to a sine wave. The source of energy should be of ample capacity.

686 **Where Ultimate Break-Down Tests** are required, these shall be made on samples not more than 6 meters (20 ft.) long. The maximum allowable temperature at which the test is made for the particular type of insulation and the particular working pressure, shall not be greater than the temperature limits given in §677.

687 **Multiple-Conductor Cables.** Each conductor of a multiple-conductor cable shall be tested against the other conductors connected together with the sheath or water.

INSULATION RESISTANCE

688 **Definition.** The insulation resistance of an insulated conductor is the electrical resistance offered by its insulation, to an impressed voltage tending to produce a leakage of current through the same.

689 **Insulation Resistance** shall be expressed in megohms for a specified length (as for a kilometer, or a mile, or one thousand feet), and shall be corrected to a temperature of 15.5° C. using a temperature coefficient determined experimentally for the insulation under consideration.

690 **Linear Insulation Resistance,** or the insulation resistance of Unit Length, shall be expressed in terms of the megohm-kilometer, or the megohm-mile, or the megohm-thousand-feet.

691 **Megohms Constant.** The Megohms Constant of an insulated conductor shall be the factor "K" in the equation

$$R = K \log_{10} \frac{D}{d}$$

where R = The insulation resistance, in megohms, for a specified unit length.

D = Outside diameter of insulation.

d = Diameter of conductor.

Unless otherwise stated, K will be assumed to correspond to the mile unit of length.

692 **Test.** The apparent insulation resistance should be measured after the dielectric-strength test, measuring the leakage current after a one-minute electrification, with a continuous e.m.f. of from 100 to 500 volts, the conductor being maintained positive to the sheath or water.

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†The Standards Committee does not commit itself to the principle of basing test voltages on working voltages, but it is not yet in possession of sufficient data to base them upon the dimensions and physical properties of the insulation.

693 **Multiple-Conductor Cables.** The insulation resistance of each conductor of a multiple-conductor cable shall be the insulation resistance measured from such conductor to all the other conductors in multiple with the sheath or water.

CAPACITANCE OR ELECTROSTATIC CAPACITY

694 **Capacitance** is ordinarily expressed in microfarads. Linear Capacitance, or Capacitance per unit length, shall be expressed in Microfarads per unit length (kilometer, or mile, or one thousand feet) and shall be corrected to a temperature of 15.5° C.

695 **Microfarads Constant.** The Microfarads Constant of an insulated conductor shall be the factor " K " in the equation

$$C = \frac{K}{\text{Log}_{10}\frac{D}{d}}$$

where C = the capacitance in microfarads per unit length.

D = the outside diameter of insulation.

d = the diameter of conductor.

Unless otherwise stated, K will be assumed to refer to the mile unit of length.

696 **Measurement of Capacitance.** The Capacitance of low-voltage cable, shall be measured by comparison with a standard condenser. For long lengths of high-voltage cables, where it is necessary to know the true capacitance, the measurement should be made at a frequency approximating the frequency of operation.

697 **Paired Cables.** The capacitance shall be measured between the two conductors of any pair, the other wires being connected to the sheath or ground.

698 **Electric Light and Power Cables.** The capacitance of low-voltage cables is generally of but little importance. The capacitance of high-voltage cables should be measured between the conductors, and also between each conductor and the other conductors connected to the lead sheath or ground.

699 **Multiple-Conductor Cables (not paired).** The capacitance of each conductor of a multiple-conductor cable shall be the capacitance measured from such conductor to all of the other conductors in multiple with the sheath or the ground.

STANDARDS FOR SWITCHES AND OTHER CIRCUIT-CONTROL APPARATUS*

SWITCHES

720 **The following Rules apply to Switches** of above 600 volts. (For 600 volts and below, see National Electric Code.†)

721 **Definition.** A switch is a device for making, breaking, or changing connections in an electric circuit.

722 **Rating.**

(a) By amperes to be carried with not more than 30 °C. rise on contacts and current-carrying parts.

(b) By normal voltage of circuit on which it may be used.

723 **Performance and Tests.**

(a) **Heating Test** with rated current applied continuously until temperature is constant; ambient temperature 40 °C.

(b) **Dielectric Test** at 2½ times rated voltage plus 2000. See §509.

CIRCUIT BREAKERS

724 **Definition.** A device designed to open a current-carrying circuit without injury to itself. A circuit breaker‡ may be:

(a) An automatic circuit-breaker, which is designed to trip automatically under any predetermined condition of the circuit, such as an underload or overload of current or voltage.

(b) A manually tripped circuit-breaker, which is designed to be tripped by hand.

Both types of operation may be combined in one and the same device.

725 **Rating.**

(a) By normal current-carrying capacity.

(b) By normal voltage.

(c) By amperes which it can interrupt at normal voltage of the circuit.

726 **Performance and Tests.** The heating test shall be made with normal current. In oil circuit breakers the same oil must be used for heating tests as for rupturing tests. The rise of temperature at the contacts shall not exceed 30 °C. The Rise on tripping solenoids and accessory parts not to exceed 50 °C. Ambient temperature of reference, 40 °C.

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*These rules do not apply to magnetically-operated or air-operated switches used for motor control.

†By the term "Code" is meant "National Electrical Code" as recommended by the National Fire Protection Association.

‡These rules refer only to circuit breakers of above 550 volts. For 550 volts and below, see the National Electric Code.

727 **Dielectric Test.** Same as §723.

728 **Rupturing Test** must be made with the current specified under §725 (c), and at normal voltage.

NOTE. Although circuit breakers should be considered as devices alone, no account being taken, in the rating, of the system on which they are to be used: yet in applying circuit breakers to any given service, it may be necessary to take into account the system on which they are to be used, with all its characteristics.

Allowances must be made for the reactance, resistance, etc., of the circuit to be controlled, as these have a direct bearing on the maximum current flow.

In some systems it has been found that the pressure rises so high during switching, that higher insulation tests than that specified in §723 should be given.

FUSES

(For circuits up to and including 600 volts, see National Electric Code)

729 **Definition.** A fuse is an element designed to melt or dissipate at a predetermined current value, and intended to protect against abnormal conditions of current.

NOTE. (The terminals, tubes, etc. which go with the fuse proper are included in the definition).

730 **Rating.** Fuses shall be rated at the maximum current which they are required to carry continuously, and at the normal voltage of the circuit on which they are designed to be used.

Fuses may be divided into two classes:

(1) Those designed to protect the circuit and apparatus both against short circuit and against definite amounts of overload (*e.g.* fuses of the National Electric Code which open on 25 per cent overload).

(2) Those designed to protect the system only against short circuits; (*e.g.* expulsion fuses, which blow at several times the current which they are designed to carry continuously). The line separating these two classes is not definitely fixed.

731 **Temperature.** Coils or windings (such as accompany fuses of the magnetic blow-out type) should not exceed the limits set for machine coils having the same character of insulation. (See §§376 to 379). The highest temperature for the fuse proper should not exceed the safe limit for the material employed (*e.g.* the temperature of the fibre tube of an enclosed fuse should not exceed the safe limit for this material, but an open-link metal fuse may be run at any temperature which will not injure the fuse material; except that no application of the above rule shall contravene the National Electric Code).

732 **Test.** For fuses intended for use on circuits of small capacity, or in protected positions on systems of large capacity, see Nation-

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NOTE. Complete standardization of these fuses above 600 volts, according to the method of the National Electric Code, is not advisable at this time, but is expected to be accomplished by an eventual extension of the National Electric Code. Until such extension is made, the following definitions and ratings may be followed.

al Electric Code. For large power fuses intended for service similar to that required of circuit breakers, see §724 to **728**, or the National Electric Code, as far as the latter applies.

LIGHTNING ARRESTERS

733 **Definition.** A lightning arrester is a device for protecting circuits and apparatus against lightning or other abnormal potential rises of short duration.

734 **Rating.** Arresters shall be rated by the voltage of the circuit on which they are to be used

Lightning arresters may be divided into two classes:

(a) Those intended to discharge for a very short time.

(b) Those intended to discharge for a period of several minutes.

735 **Performance and Tests.** Dielectric Test same as §**723**.

The resistance of the arrester at double potential and also at normal potential, shall be determined by observing the discharge currents through the arrester.

(c) In the case of any arrester using a gap, a test shall be made of the spark potential on either direct-current or 60-cycle a-c. excitation.

(d) The equivalent sphere gap under disruptive discharge shall also be measured, using a considerable quantity of electricity.

(e) The endurance of the arrester to continuous surges shall be tested.

PROTECTIVE REACTORS

736 **Definition.** A reactor (See §**82** and **214**) is a device for protecting circuits by limiting the current flow and localizing the disturbance under short-circuit conditions.

737 **Rating.**

(a) In kilovolt-amperes absorbed by normal current.

(b) By the normal current, frequency and line (delta) voltage for which the reactor is designed.

(c) By the current which the device is required to stand under short-circuit conditions.

738 **Performance and Tests.**

The Heat Test shall be made with normal current and frequency applied until the temperature is constant. The temperature should not exceed the safe limits for the materials employed. See §§**376** to **379**.

739 **Dielectric Test.** 2½ times line voltage plus 2000, for one minute, from conductor to ground.

NOTE. The reactor shall be so designed as to be capable of withstanding, without mechanical injury, rated current at normal frequency, suddenly applied.

RESISTOR OR RHEOSTAT

740 **Definition.** Any device heretofore commonly known as a resistance, used for operation or control. (§**81**) See National Electric Code.

INSTRUMENT TRANSFORMERS

741 **Definition.** An instrument transformer is a transformer for use with measuring instruments, in which the conditions in the primary circuit as to current and voltage are represented with high numerical accuracy in the secondary circuit.

Under this heading and for more general use:

(a) A current transformer is a transformer designed for series connection in its primary circuit with the ratio of transformation appearing as a ratio of currents.

(b) A potential (voltage) transformer is a transformer designed for shunt or parallel connection in its primary circuit, with the ratio of transformation appearing as a ratio of potential differences (voltages).

For further definitions relative to instrument transformers, see **205-207.**

For the dielectric test of potential transformers, see **§500**, and for the dielectric test of current transformers, see **§509.**

Further standards concerning instrument transformers are still under discussion.

STANDARDS FOR ELECTRIC RAILWAYS

DEFINITIONS

760 **Transmission System:** When the current generated for an electric railway is changed in kind or voltage, between the generator and the cars or locomotives, that portion of the conductor system carrying current of a kind or voltage substantially different from that received by the cars or locomotives, constitutes the *transmission system.**

761 **Distribution System:** That portion of the conductor system of an electric railway which carries current of the kind and voltage received by the cars or locomotives, constitutes the *distribution system.**

762 **Substation:** A substation is a group of apparatus or machinery which receives current from a transmission system, changes its kind or voltage, and delivers it to a distribution system.

RATING OF RAILWAY SUBSTATION MACHINERY

763 **Continuous Rating.** The rating of a substation machine shall be the kv-a. output at a stated power factor input, which it will deliver continuously with temperatures or temperature rises not exceeding the limiting values given in Sections 376 and 379 and also fulfilling the other requirements set forth in these rules and summarized in Section 260.

764 **Momentary Loads.** These machines should be capable of carrying a load of twice their rating for one minute, after a continuous run at rated load, without disqualifying them for continuous service.

765 **Nominal Rating.** Where the continuous rating is inconvenient, the following nominal rating may be used. The nominal rating of a substation machine shall be the kv-a. output at a stated power factor input, which, having produced a constant temperature in the machine may be increased 50 per cent for two hours, without producing temperatures or temperature rises exceeding by more than 5°C. the limiting values given in §376 and 379. These machines should be capable of carrying a load of twice their nominal rating for a period of one minute, without disqualifying them for continuous service. The name plate should be marked " nominal rating."

CONDUCTOR AND RAIL SYSTEMS.

766 **Contact Conductors.** That part of the distribution system other than the traffic rails, which is in immediate electrical contact with

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*These definitions are identical in sense, although not in words, with those of the Interstate Commerce Commission, as given in their Classification of Accounts for Electric Railways.

the circuits of the cars or locomotives, constitutes the contact conductors.

767 **Contact Rail:** A rigid contact conductor.

768 Overhead Contact Rail: A contact rail above the elevation of the maximum equipment line.†

769 Third Rail: A contact conductor placed at either side of the track, the contact surface of which is a few inches above the level of the top of the track rails.

770 Center Contact Rail: A contact conductor placed between the track rails, having its contact surface above the ground level.

771 Underground Contact Rail: A contact conductor placed beneath the ground level.

772 Gage of Third Rail: The distance, measured parallel to the plane of running rails, between the gage line of the nearer track rail and the inside gage line of the *contact surface* of the third rail.

773 Elevation of Third Rail: The elevation of the contact-surface of the third rail, with respect to the plane of the tops of running rails.

774 Standard Gage of Third Rails: The gage of third rails shall be not less than 26 inches (66 cm.) and not more than 27 inches (68.6 cm.).

775 Standard Elevation of Third Rails: The elevation of third rails shall be not less than 2¾ inches (70 mm.), and not more than 3½ inches (89 mm.).

776 Third Rail Protection: A guard for the purpose of preventing accidental contact with the third rail.

777 **Trolley Wire:** A flexible contact conductor, customarily supported above the cars.

778 **Messenger Wire or Cable:** A wire or cable running along with and supporting other wires, cables or contact conductors.

A primary messenger is directly attached to the supporting system. A secondary messenger is intermediate between a primary messenger and the wires, cables or contact conductors.

779 **Classes of Construction:** Overhead trolley construction will be classed as *Direct Suspension* and *Messenger or Catenary Suspension.*

780 Direct Suspension: All forms of overhead trolley construction in which the trolley wires are attached, by insulating devices, directly to the main supporting system.

781 Messenger or Catenary Suspension: All forms of overhead trolley construction in which the trolley wires are attached, by suitable devices, to one or more messenger cables, which in turn may be carried either in *Simple Catenary, i.e.*, by primary messengers, or in *Compound Catenary, i.e.*, by secondary messengers.

782 Supporting Systems shall be classed as follows:

783 Simple Cross-Span Systems: Those systems having at each support a single flexible span across the track or tracks.

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†The contour which embraces cross-sections of all rolling stock under all normal operating conditions.

784 Messenger Cross-Span Systems: Those systems having at each support two or more flexible spans across the track or tracks, the upper span carrying part or all of the vertical load of the lower span.

785 Bracket Systems: Those systems having at each support an arm or similar rigid member, supported at only one side of the track or tracks.

786 Bridge Systems: Those systems having at each support a rigid member, supported at both sides of the track or tracks.

787 Standard Height of Trolley Wire on Street and Interurban Railways: It is recommended that supporting structures shall be of such height that the lowest point of the trolley wire shall be at a height of 18 feet (5.5m.) above the top of rail under conditions of maximum sag, unless local conditions prevent. On trackage operating electric and steam road equipment and at crossings over steam roads, it is recommended that the trolley wire shall be not less than 21 feet (6.4m.) above the top of rail, under conditions of maximum sag.

RAILWAY MOTORS

RATING

800 **Nominal Rating:** The nominal rating of a railway motor shall be the mechanical output at the car or locomotive axle, measured in kilowatts, which causes a rise of temperature above the surrounding air, by thermometer, not exceeding 90 °C. at the commutator, and 75 °C. at any other normally accessible part after one hour's continuous run at its rated voltage (and frequency in the case of an alternating-current motor) on a stand with the motor covers arranged to secure maximum ventilation without external blower. The rise in temperature as measured by resistance, shall not exceed 100 °C.*

801 The statement of the nominal rating shall also include the corresponding voltage and armature speed.

802 **Continuous Rating:** The continuous ratings of a railway motor shall be the *inputs* in amperes at which it may be operated continuously at ½, ¾ and full voltage respectively, without exceeding the specified temperature rises (see §805), when operated on stand test with motor covers and cooling system, if any, arranged as in service. Inasmuch as the same motor may be operated under different conditions as regards ventilation, it will be necessary in each case to

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*This definition differs from that in the 1911 edition of the Rules, principally by the substitution of a kilowatt rating for the horse-power rating and the omission of a reference to a room temperature of 25 °C. The horse-power rating of a railway motor may, for practical purposes, be taken as $\frac{4}{3}$ of the kilowatt rating. On account of the hitherto prevailing practise of expressing mechanical output in horse-power, it is recommended that, for the present, the capacity be expressed both in kilowatts and in horse-power, a double rating, namely,

kw.————approx. equiv. h.p.————

In order to lay stress upon the preferred future basis, it is desirable that on rating plates, the rating in kilowatts shall be shown in larger and more prominent characters than the capacity in horse power.

define the system of ventilation which is used. In case motors are cooled by external blowers, the flow of air on which the rating is based shall be given.

803 **Maximum Input.** The subject of momentary loads for railway motors is under investigation.

TEMPERATURE LIMITATIONS

804 **The allowable temperature** in any part of a motor in service will be governed by the kind of material with which that part is insulated. In view of space limitations, and the cost of carrying dead weight on cars, it is considered good practice to operate railway motors for short periods at higher temperatures than would be advisable in stationary motors. The following temperatures are permissible:

TABLE XV
Operating Temperatures of Railway Motors

Class of Material See §376 to 379.	Maximum Observable Temperature of windings when in continuous service.	
	By Thermometer See §345	By Resistance
A	85	110
B	100	130

For infrequent occasions, due to extreme ambient temperatures, it is permissible to operate at 15° higher temperature.

805 With a view to not exceeding the above temperature limitations, the continuous ratings shall be based upon the temperature rises tabulated below:

TABLE XVI
Stand-Test Temperature Rises of Railway Motors*

Class of Material See §376 to 379	Temperature Rises of windings	
	By Thermometer See §345	By Resistance
A	65	85
B	80	105

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*The temperature rise in service may be very different from that on stand test. See §1104 for relation between stand test and service temperatures, as affected by ventilation.

806 **Field-Control Motors.** The nominal and continuous ratings of field-control motors shall relate to their performance with the operating field which gives the maximum motor rating. Each section of the field windings shall be adequate to perform the service required of it, without exceeding the specified temperature rises.

CHARACTERISTIC CURVES

810 **The Characteristic Curves** of railway motors shall be plotted with the current as abscissas and the tractive effort, speed and efficiency as ordinates. In the case of a-c. motors, the power factor shall also be plotted as ordinates.

811 **Characteristic curves of direct-current motors** shall be based upon full voltage, which shall be taken as 600 volts, or a multiple thereof.

812 **In the case of field-control motors,** characteristic curves shall be given for all operating field connections.

EFFICIENCY AND LOSSES

815 **The efficiency** of railway motors shall be deduced from a determination of the losses enumerated in **§816** to **820.** (See also **§ 1100** and **1101.**)

816 **The copper loss** shall be determined from resistance measurements corrected to 75° C.

817 **The no-load core loss, brush friction, armature-bearing friction and windage** shall be determined as a total under the following conditions:

In making the test, the motor shall be run without gears. The kind of brushes and the brush pressure shall be the same as in commercial service. With the field separately excited, such a voltage shall be applied to the armature terminals as will give the same speed for any given field current as is obtained with that field current when operating at normal voltage under load. The sum of the losses above-mentioned, is equal to the product of the counter-electromotive force and the armature current.

818 **The core loss** in d-c. motors shall be separated from the friction and windage losses above described by measuring the power required to drive the motor at any given speed without gears, by running it as a series motor on low voltage and deducting this loss from the sum of the no-load losses at corresponding speed. (See **§1101** for alternative method).

The friction and windage losses under load shall be assumed to be the same as without load, at the same speed.

The core loss under load shall be assumed as follows:

TABLE XVII

Core Loss in D. C. Railway Motors at Various Loads.

Per cent of Input at Nominal Rating	Loss as Per cent of No-load Core Loss
200	165
150	145
100	130
75	125
50	123
25 and under	122

Note:—With motors designed for field control the core losses shall be assumed as the same for both full and permanent field. It shall be the mean between the no-load losses at full and permanent field, increased by the percentages given in the above Table.

819 **The brush-contact resistance loss** to be used in determining the efficiency, may be obtained by assuming that the sum of the drops at the contact surfaces of the positive and negative brushes is three volts.

820 The losses in gearing and axle bearings for single-reduction single-geared motors, varies with type, mechanical finish, age and lubrication. The following values, based on accumulated tests, shall be used in the comparison of single-reduction single-geared motors.

TABLE XVIII

Losses in Axle Bearings and Single-Reduction Gearing of Railway Motors.

Per Cent of Input at Nominal Rating	Losses as Per Cent of Input
200	3.5
150	3.0
125	2.7
100	2.5
75	2.5
60	2.7
50	3.2
40	4.4
30	6.7
25	8.5

Note:—Further investigation may indicate the desirability of giving separate values of the losses for full and tapped fields, or low- and high-speed motors.

ELECTRIC LOCOMOTIVES

830 **Rating.** Locomotives shall be rated in terms of the weight on drivers, nominal one-hour tractive effort, continuous tractive effort and corresponding speeds.

831 **Weight on Drivers.** The weight on drivers, expressed in pounds, shall be the sum of the weights carried by the drivers and of the drivers themselves.

832 **Nominal Tractive Effort:** The nominal tractive effort, expressed in pounds, shall be that exerted at the rims of the drivers, when the motors are operating at their nominal (one-hour) rating.

833 **Continuous Tractive Effort.** The continuous tractive effort, expressed in pounds, shall be that exerted at the rims of the drivers when the motors are operating at their full-voltage continuous rating, as indicated in §802.

In the case of locomotives operating on intermittent service, the continuous tractive effort may be given for ½ or ¾ voltage, but in such cases the voltage shall be clearly specified.

834 **Speed:** The rated speed, expressed in miles per hour, shall be that at which the continuous tractive effort is exerted.

See also Appendix II on Additional Standards for Railway Motors.

ILLUMINATION AND PHOTOMETRY

The following Sections, **850** to **895**, are the rules of the Nomenclature and Standards Committee of the Illuminating Engineering Society. They are here included by permission.

850 **Luminous flux** is radiant power evaluated according to its capacity to produce the sensation of light.

851 **The stimulus coefficient** K_λ for radiation of a particular wave-length, is the ratio of the luminous flux to the radiant power producing it.

852 **The mean value of the stimulus coefficient,** K_m, over any range of wave-lengths, or for the whole visible spectrum of any source, is the ratio of the total luminous flux (in lumens) to the total radiant power (in ergs per second, but more commonly in watts).

853 **The luminous intensity** of a point source of light is the solid angular density of the luminous flux emitted by the source in the direction considered; or it is the flux per unit solid angle from that source.

Defining equation:

Let I be the intensity, F the flux and ω the solid angle.

Then
$$I = \frac{dF}{d\omega}$$

or, if the intensity is uniform,
$$I = \frac{F}{\omega},$$

854 **Illumination,** on a surface, is the luminous flux-density over that surface, or the flux per unit of intercepting area.

Defining equation:

Let E be the illumination and S the area of the intercepting surface.

Then
$$E = \frac{dF}{dS},$$

or, when uniform,
$$E = \frac{F}{S},$$

855 **Candle,** the unit of luminous intensity maintained by the National Laboratories of France, Great Britain, and the United States.[1]

856 **Candle-power,** luminous intensity expressed in candles.

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[1] This unit, which is used also by many other countries, is frequently referred to as the international candle.

857 **Lumen,** the unit of luminous flux, equal to the flux emitted in a unit solid angle (steradian) by a point source of one candle-power.[2]

858 **Lux,** a unit of illumination equal to one lumen per square meter. The C. G. S. unit of illumination is one lumen per square centimeter. For this unit Blondel has proposed the name "Phot." One milli-lumen per square centimeter (milliphot) is a practical derivative of the C. G. S. system. One foot-candle is one lumen per square foot and is equal to 1.0764 milliphots.

859 **Exposure,** the product of an illumination by the time. Blondel has proposed the name "phot-second" for the unit of exposure in the C. G. S. system.

860 **Specific luminous radiation,** the luminous flux-density emitted by a surface, or the flux emitted per unit of emissive area. It is expressed in lumens per square centimeter.

Defining equation:

Let E′ be the specific luminous radiation.

Then, for surfaces obeying Lambert's cosine law of emission.

$$E' = \pi b_0.$$

861 **Brightness,** b, of an element of a luminous surface from a given position, may be expressed in terms of the luminous intensity per unit area of the surface projected on a plane perpendicular to the line of sight, and including only a surface of dimensions negligibly small in comparison with the distance to the observer. It is measured in candles per square centimeter of the projected area.

Defining equation:

Let θ be the angle between the normal to the surface and the line of sight.

Then $$b = \frac{dI}{dS\ \cos\theta}$$

862 **Normal brightness,** b_0, of an element of a surface (sometimes called specific luminous intensity) is the brightness taken in a direction normal to the surface.[3]

Defining equation:

$$b_0 = \frac{dI}{dS},$$

or, when uniform, $$b_0 = \frac{I}{S}$$

Brightness may also be expressed in terms of the specific luminous radiation of an ideal surface of perfect diffusing qualities, *i. e.*, one obeying Lambert's cosine law.

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[2] A uniform source of one candle emits 4π lumens.

[3] In practice, the brightness b of a luminous surface or element thereof is observed, and not the normal brightness b_0. For surfaces for which the cosine law of emission holds, the quantities b and b_0 are equal.

863 **The Lambert, the C. G. S. Unit of Brightness,** the brightness of a perfectly diffusing surface radiating or reflecting one lumen per square centimeter. This is equivalent to the brightness of a perfectly diffusing surface having a coefficient of reflection equal to unity and illuminated by one phot.

864 **For most purposes, the millilambert** (0.001 lambert) is the preferable practical unit. A perfectly diffusing surface emitting one lumen per square foot will have a brightness of 1.076 millilamberts.

865 **Brightness expressed in candles per square centimeter** may be reduced to Lamberts by multiplying by π.

Brightness expressed in candles per square inch may be reduced to foot-candle brightness, by multiplying by the factor $144\,\pi = 452$.

Brightness expressed in candles per square inch may be reduced to lamberts by multiplying by $\pi/6.45 = 0.4868$.

In practice, no surface obeys exactly Lambert's cosine law of emission; hence the brightness of a surface in lamberts is, in general not numerically equal to its specific luminous radiation in lumens per square centimeter.

Defining equations:

$$L = \frac{dF}{dS}$$

Or when uniform

$$L = \frac{F}{S}$$

866 **Coefficient of reflection,** the ratio of the total luminous flux reflected by a surface to the total luminous flux incident upon it. It is a simple numeric. The reflection from a surface may be regular, diffuse or mixed. In perfect regular reflection, all of the flux is reflected from the surface at an angle of reflection equal to the angle of incidence. In perfect diffuse reflection, the flux is reflected from the surface in all directions, in accordance with Lambert's cosine law. In most practical cases, there is a superposition of regular and diffuse reflection.

867 **Coefficient of regular reflection** is the ratio of the luminous flux reflected regularly to the total incident flux.

868 **Coefficient of diffuse reflection** is the ratio of the luminous flux reflected diffusely to the total incident flux.

Defining equation:

Let m be the coefficient of reflection (regular or diffuse).

Then, for any given portion of the surface,

$$m = \frac{E'}{E}$$

869 **Lamp,** a generic term for an artificial source of light.

870 **Primary luminous standard**, a recognized standard luminous source reproducible from specifications.

871 **Representative luminous standard**, a standard of luminous intensity adopted as the authoritative custodian of the accepted value of the unit.

872 **Reference standard**, a standard calibrated in terms of the unit from either a primary or representative standard and used for the calibration of working standards.

873 **Working standard**, any standardized luminous source for daily use in photometry.

874 **Comparison lamp**, a lamp of constant but not necessarily known candle-power, against which a working standard and test lamps are successively compared in a photometer.

875 **Test lamp**, in a photometer,—a lamp to be tested.

876 **Performance curve**, a curve representing the behavior of a lamp in any particular (candle-power, consumption, etc.) at different periods during its life.

877 **Characteristic curve**, a curve expressing a relation between two variable properties of a luminous source, as candle-power and volts, candle-power and rate of fuel consumption, etc.

878 **Horizontal Distribution Curve.** A polar curve representing the luminous intensity of a lamp, or lighting unit, in a plane perpendicular to the axis of the unit, and with the unit at the origin.

879 **Vertical Distribution Curve.** A polar curve representing the luminous intensity of a lamp, or lighting unit, in a plane passing through the axis of the unit, and with the unit at the origin. Unless otherwise specified, a vertical distribution curve is assumed to be an *average* vertical distribution curve, such as may in many cases be obtained by rotating the unit about its axis and measuring the average intensities at the different elevations. It is recommended that in vertical distribution curves, angles of elevation shall be counted positively from the nadir as zero, to the zenith as 180 degrees. In the case of incandescent lamps, it is assumed that the vertical distribution curve is taken with the tip downward.

880 **Mean horizontal candle-power** of a lamp,—the average candle-power in the horizontal plane passing through the luminous center of the lamp.

It is here assumed that the lamp (or other light source) is mounted in the usual manner, or, as in the case of an incandescent lamp, with its axis of symmetry vertical.

881 **Mean spherical candle-power** of a lamp,—the average candle-power of a lamp in all directions in space. It is equal to the total luminous flux of the lamp, in lumens, divided by 4π.

882 **Mean hemispherical candle-power** of a lamp (upper or lower),—the average candle-power of a lamp in the hemisphere considered. It is equal to the total luminous flux emitted by the lamp, in that hemisphere, divided by 2π.

883 **Mean zonal candle-power** of a lamp,—the average candle-power of a lamp over the given zone. It is equal to the total luminous flux emitted by the lamp in that zone, divided by the solid angle of the zone.

884 **Spherical reduction factor** of a lamp,—the ratio of the mean spherical to the mean horizontal candle-power of the lamp.[4]

885 **Photometric Tests** in which the results are stated in candle-power should be made at such a distance from the source of light that the latter may be regarded as practically a point. Where tests are made in the measurement of lamps with reflectors, the results should always be given as "apparent candle-power" at the distance employed, which distance should always be specifically stated.

886 **The output of all illuminants** should be expressed in lumens.

887 **Illuminants should be rated** upon a lumen basis instead of a candle-power basis.

888 **The specific output of electric lamps** should be stated in lumens per watt; and the specific output of illuminants depending upon combustion should be stated in lumens per b.t.u. per hour. The use of the term "efficiency" in this connection should be discouraged.

When auxiliary devices are necessarily employed in circuit with a lamp, the input should be taken to include both that in the lamp and that in the auxiliary devices. For example, the watts lost in the ballast resistance of an arc lamp are properly chargeable to the lamp.

889 **The Specific Consumption** of an electric lamp is its watt consumption per lumen. "Watts per candle" is a term used commercially in connection with electric incandescent lamps, and denotes, watts per mean horizontal candle-power.

890 **Life Tests. Electric Incandescent Lamps** of a given type may be assumed to operate under comparable conditions only when their lumens per watt consumed are the same. Life-test results, in order to be compared, must be either conducted under, or reduced to, comparable conditions of operation.

891 **In Comparing Different Luminous Sources,** not only should their candle-power be compared, but also their relative form, brightness, distribution of illumination and character of light.

892 **Lamp Accessories. A reflector** is an appliance, the chief use of which is to redirect the luminous flux of a lamp in a desired direction or directions.

893 **A Shade** is an appliance, the chief use of which is to diminish or to interrupt the flux of a lamp in certain directions, where such flux is not desirable. The function of a shade is commonly combined with that of a reflector.

894 **A Globe** is an enclosing appliance of clear or diffusing materials, the chief use of which is either to protect the lamp, or to diffuse its light.

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[4] In case of a uniform point-source, this factor would be unity, and for a straight cylindrical filament obeying the cosine law it would be $\pi/4$.

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TABLE XIX.

Photometric Units and Abbreviations.

Photometric quantity	Name of unit	Abbreviations, Symbols and defining equations
1. Luminous flux	Lumen	F, Ψ
2. Luminous intensity	Candle	$I = \frac{dF}{d\omega}, \Gamma = \frac{d\Psi}{d\omega}$, cp.
3. Illumination	Phot., foot-candle, lux	$E = \frac{dF}{dS} = \frac{I}{r^2}\cos\theta.\beta$
4. Exposure	Phot-second	$\epsilon \quad t \quad E$
5. Brightness	Apparent candles per sq. cm. Apparent candles per sq. in.	$b = \frac{dI}{dS\ \cos\ \theta}$
	Lambert	$L = \frac{dF}{dS}$
6. Normal brightness	Candles per sq. cm. Candles per sq. in.	$b_0 = \frac{dI}{dS}$
7. Specific luminous radiation	Lumens per sq. cm. Lumens per sq. in.	$E' = \pi b_0 \beta'$
8. Coefficient of reflection	—	$m = \frac{E'}{E}$

9. Mean spherical candlepower	scp
10. Mean lower hemispherical candlepower	lcp
11. Mean upper hemispherical candlepower	ucp
12. Mean zonal candlepower	zcp

13. 1 lumen is emitted by 0.07958 spherical cp.
14. 1 spherical candlepower emits 12.57 lumens.
15. 1 lux = 1 lumen incident per square meter = 0.0001 phot = 0.1 milliphot.
16. 1 phot = 1 lumen incident per sq. cm. = 10.000 lux = 1000 milliphot.
17. 1 milliphot = 0.001 phot = 0.929 foot-candle.
18. 1 foot-candle = 1 lumen incident per square foot = 1.076 milliphot = 10.76 lux.
19. 1 lambert = 1 lumen emitted per square centimeter.*
20. 1 millilambert = 0.001 lambert.
21. 1 lumen, emitted, per square foot* = 1.076 millilambert.
22. 1 millilambert = 0.929 lumen, emitted, per square foot*.
23. 1 lambert = 0.3183 candle per sq. cm. = 2.054 candles per sq. in.
24. 1 candle per sq. cm. = 3.1416 lamberts.
25. 1 candle per sq. in.. = 0.4868 lamberts = 486.8 millilamberts.

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*Perfect diffusion assumed.

SYMBOLS.

896 In view of the fact that the symbols heretofore proposed by this committee conflict in some cases with symbols adopted for electric units by the International Electrotechnical Commission, it is proposed that where the possibility of any confusion exists in the use of electrical and photometric symbols, an alternative system of symbols for photometric quantities should be employed. These should be derived exclusively from the Greek alphabet, for instance:

Luminous intensity	Γ
Luminous flux	Ψ
Illumination	β

STANDARDS FOR TELEPHONY AND TELEGRAPHY

910 After careful consideration, it does not seem that the time is yet ripe for a formal standardization of terms and definitions used in telephony and telegraphy. Many of the terms commonly employed are used in more than a single way, and conversely, many pieces of apparatus and many constants which are essentially identical from a physical standpoint have been and are known by more than one designation.

911 **Damping of a Circuit.** The damping, at a given point, in a circuit from which the source of energy has been withdrawn, is the progressive diminution in the effective value of electromotive force and current at that point resulting from the withdrawal of electrical energy.

912 **Damping Constant.** The damping constant of a circuit depends upon the ratio of the dissipative to the reactive component of its impedance or admittance.

Applied to the admittance of a condenser or other simple circuit having capacity reactance, the damping constant for a harmonic electromotive force of given frequency is the ratio of the conductance of the condenser or simple circuit at that frequency, to twice the capacity of the condenser at the same frequency.

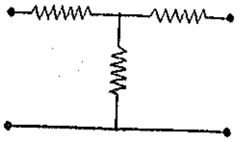
Applied to the reactance of a coil or other simple circuit having inductive reactance, the damping constant for a harmonic current of given frequency is the ratio of the resistance of the coil or circuit at that frequency, to twice the inductance at the same frequency.

913 **Equivalent Circuit.** An equivalent circuit is a simple network of series and shunt impedances, which, at a given frequency, is the approximate electrical equivalent of a complex network at the same frequency and under steady-state conditions.

NOTE: As ordinarily considered, the simple networks as defined, are the electrical equivalents of complex networks only with respect to definite pairs of terminals, and only as to sending-end impedances, and total attenuation. A further requirement is that the only connections between the pairs of terminals are those through the network itself.

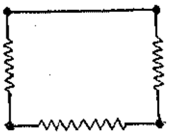
914 **"T" Equivalent Circuit.** A "T" equivalent circuit is a triple-star or "Y" connection of three impedances externally equivalent to a complex network.

Symbol:



915 **"U" Equivalent Circuit.** A "U" equivalent circuit is a delta connection of three impedances externally equivalent to a complex network. It is also called a "Π" equivalent circuit.

Symbol:



IMPEDANCE

916 **Mutual Impedance.** The mutual impedance, for alternating currents, between a pair of terminals and a second pair of terminals of a network, under any given condition, is the negative vector ratio of the electromotive force produced between either pair of terminals on open circuit, to the current flowing between the other pair of terminals.

917 **Self Impedance.** The self impedance between a pair of terminals of a network, under any given condition, is the vector ratio of the electromotive force applied across the terminals to the current produced between them.

LINE CHARACTERISTICS

918 **Characteristic Impedance.** The characteristic impedance of a line is the ratio of the applied electromotive force to the resulting steady-state current upon a line of infinite length and uniform structure, or of periodic recurrent structure.

NOTE: In telephone practice, the terms (1) line impedance, (2) surge impedance, (3) iterative impedance, (4) sending-end impedance, (5) initial sending-end impedance, (6) final sending-end impedance, (7) natural impedance and (8) free impedance, have apparently been more or less indefinitely and indiscriminately used as synonyms with what is here defined as "characteristic impedance."

919 **Sending-End Impedance.** The sending-end impedance of a line is the vector ratio of the applied electromotive force to the resulting steady-state current at the point where the electromotive force is applied.

NOTE: See note under "Characteristic Impedance." In case the line is of infinite length of uniform structure or of periodic recurrent structure, the sending-end impedance and the characteristic impedance are the same.

920 **Propagation Constant.** The propagation constant per unit length of a uniform line, or per section of a line of periodic recurrent structure, is the natural logarithm of the vector ratio of the steady-state currents at various points separated by unit length in a uniform line of infinite length, or at successive corresponding points in a line of recurrent structure of infinite length. The ratio is determined by dividing the value of the current at the point nearer the transmitting end by the value of the current at the point more remote.

921 **Attenuation Constant.** The attenuation constant is the real part of the propagation constant.

922 **Wave-Length Constant.** The wave-length constant is the imaginary part of the propagation constant.

LINE CIRCUITS

930 **Ground-Return Circuit.** A ground-return circuit is a circuit consisting of one or more metallic conductors in parallel, with the circuit completed through the earth.

931 **Metallic Circuit.** A metallic circuit is a circuit of which the earth forms no part.

932 **Two-Wire Circuit.** A two-wire circuit is a metallic circuit formed by two paralleling conductors insulated from each other.

933 **Superposed Circuit.** A superposed circuit is an additional circuit obtained from a circuit normally required for another service, and in such a manner that the two services can be given simultaneously without mutual interference.

934 **Phantom Circuit.** A phantom circuit is a superposed circuit, each side of which consists of the two conductors of a two-wire circuit in parallel.

935 **Side Circuit.** A side circuit is a two-wire circuit forming one side of a phantom circuit.

936 **Non-Phantomed Circuit.** A non-phantomed circuit is a two-wire circuit, which is not arranged for use as the side of a phantom circuit.

937 **Simplexed Circuit.** A simplexed circuit is a two-wire telephone circuit, arranged for the super-position of a single ground-return signalling circuit-operating over the wires in parallel.

Note: In view of the use of the term "Simplex Operation" in telegraph practice, it is felt that the designation "Simplexed Circuit" as applied to the arrangement described is not a happy one.

938 **Composited Circuit.** A composited circuit is a two-wire telephone circuit, arranged for the superposition on each of its component metallic conductors, of a single independent ground-return signalling circuit.

939 **Quadded or Phantomed Cable.** A quadded or phantomed cable is a cable adapted for the use of phantom circuits.

Note: The type of cable here defined has frequently been designated as "Duplex Cable"—a term which is objectionable, both on account of its lack of description and its widely different use in telegraph practice.

LOADING

950 **Loaded Line.** A loaded line is one in which the normal inductance of the circuit has been altered for the purpose of increasing its transmission efficiency for one or more frequencies.

951 **Series Loaded Line.** A series loaded line is one in which the normal inductance has been altered by inductance serially applied.

952 **Shunt Loaded Line.** A shunt loaded line is one in which the normal inductance of the circuit has been altered by inductance applied in shunt across the circuit.

953 **Continuous Loading.** A continuous loading is a series loading in which the added inductance is uniformly distributed along the conductors.

954 **Coil Loading.** A coil loading is one in which the normal inductance is altered by the insertion of lumped inductance in the circuit at intervals. This lumped inductance may be applied either in series or in shunt.

NOTE: As commonly understood, coil loading is a series loading, in which the lumped inductance is applied at uniformly spaced recurring intervals

955 **Microphone.** A contact device designed to have its electrical resistance directly and materially altered by slight differences in mechanical pressure.

956 **Relay.** A relay is a device by means of which contacts in one circuit are operated under the control of electrical energy in the same or other circuits.

957 **Resonance.** Resonance of a harmonic alternating current of given frequency, in a simple series circuit, containing resistance, inductance and capacity, is the condition in which the positive reactance of the inductance is numerically equal to the negative reactance of the capacity. Under these conditions, the current flow in the circuit with a given electromotive force is a maximum.

958 **Retardation Coil.** A retardation coil is a reactor (reactance coil) used in a circuit for the purpose of selectively reacting on currents which vary at different rates.

NOTE: In telephone and telegraph usage, the terms "impedance coil," "inductance coil," choke coil" and "reactance coil" are sometimes used in place of the term "retardation coil."

959 **Skin Effect.** Skin effect is the phenomenon of the non-uniform distribution of current throughout the cross-section of a linear conductor, occasioned by variations in the intensity of the magnetic field due to the current in the conductor.

960 **Telephone Receiver.** A telephone receiver is an electrically operated device, designed to produce sound waves or vibrations which correspond in form to the electromagnetic waves or vibrations actuating it.

961 **Telephone Transmitter.** A telephone transmitter is a sound-wave or vibration-operated device designed to produce electromagnetic waves or vibrations which correspond in form to the sound waves or vibrations actuating it.

962 **The Coefficient of Coupling of a Transformer.** The coefficient of coupling of a transformer at a given frequency, is the vector ratio of the mutual impedance between the primary and secondary of the transformer, to the square root of the product of the self-impedances of the primary and of the secondary.

963 **Repeating Coil.** A term used in telephone practice meaning the same as transformer, and ordinarily a transformer of unity ratio.

APPENDIX I.

STANDARDS FOR RADIO COMMUNICATION

The following Sections **1000** to **1033** have been prepared by the Standardization Committee of the Institute of Radio Engineers, and are here included by permission as an Appendix, until further revised.

1000 **Acoustic Resonance Device.** One which utilizes, in its operation, resonance to the audio frequency of the received impulses.

1001 **Antenna.** A system of conductors designed for radiating or absorbing the energy of electromagnetic waves.

1002 **Atmospheric Absorption.** That portion of the total loss of radiated energy due to atmospheric conductivity.

1003 **Audio Frequencies.** The normally audible frequencies lying below 20,000 cycles per second (see also radio frequencies).

1004 **Capacitive Coupler.** An apparatus which, by electric fields, joins portions of two radio frequency circuits and is used to transfer electrical energy between these circuits through the action of electric forces.

1005 **Coefficient of Coupling (Inductive).** The ratio of the effective mutual inductance of two circuits to the square root of the product of the effective self-inductances of each of these circuits.

1006 **Direct Coupler.** An apparatus which magnetically joins two circuits having a common conductive portion and which is used to transfer electrical energy between these circuits.

1007 **Counterpoise.** A system of electrical conductors insulated from ground forming one plate of a condenser, the other plate of which is the antenna. In land stations a counterpoise forms a capacitive connection to ground.

1008 **A Damped Alternating Current** is a current which alternates regularly in direction and whose amplitude progressively diminishes.

1009 **The Damping Factor** of an exponentially damped alternating current is the product of the logarithmic decrement and the frequency.

Let I_0 = initial amplitude
I_t = amplitude at the time t
ϵ = base of Napierian logarithms
a = damping factor
Then: $I_t = I_0 \, \epsilon^{-at}$

1010 **Detector.** That portion of the receiving apparatus which, connected to a circuit carrying currents of radio frequency, and in conjunction with a self-contained or separate indicator, translates the radio frequency energy into a form suitable for operation of the indicator. This translation may be effected either by the conversion of the radio frequency energy, or by means of the control of local energy by the energy received.

1011 **Electromagnetic Wave.** A progressive disturbance characterized by the existence on the wave front of electric and magnetic forces acting in directions which are perpendicular to each other and to the direction of propagation of the wave.

1012 **Forced Alternating Current.** A current produced in any circuit by the application of an alternating electromotive force.

1013 **Free Alternating Current.** A current produced by means of an electromagnetic disturbance in a circuit, having capacity, inductance, and *less* than the critical resistance.

1014 **Critical Resistance of a Circuit** determines the limit between the oscillatory and aperiodic discharge of that circuit. (The discharge is aperiodic if the circuit resistance is greater than the critical value and is alternating when the resistance is less than the critical value). In a circuit without dielectric or magnetic hysteresis, the critical resistance equals $2\sqrt{\frac{L}{C}}$, where L and C are the effective inductance and capacity of the circuit.

1015 **Group Frequency.** The number per second of periodic changes in amplitude or frequency of an alternating current.

NOTE 1. Where there is more than one periodic recurrent change of amplitude or frequency, there is more than one group frequency present.

NOTE 2. The term "group frequency" replaces the term "spark frequency."

1016 **Inductive Coupler.** An apparatus which, by magnetic forces, joins portions of two radio frequency circuits and is used to transfer electrical energy between these circuits, through the action of magnetic forces.

1017 **Linear Decrement of a Linearly Damped Alternating Current** is the difference of successive current amplitudes in the same direction, divided by the larger of these amplitudes.

Let: I_n and I_{n+1} be successive current amplitudes in the same direction, of a linearly-damped alternating current.

Then: The linear decrement, $b = \frac{I_n - I_{n+1}}{I_n}$

Also: $I_t = I_0 (1 - bft)$

Where: I_0 = initial current amplitude
I_t = current amplitude at time t
f = frequency of alternating current

1018 **Logarithmic Decrement** of an exponentially damped alternating current is the logarithm of the ratio of successive current amplitudes in the same direction.

NOTE: Logarithmic decrements are standard for a complete period or cycle.

Let: I_n and I_{n+1} be successive current amplitudes in the same direction.

d = logarithmic decrement

Then: $$d = \log_\epsilon \frac{I_n}{I_{n+1}}$$

1019 **Radio Frequencies.** Those above 20,000 cycles per second (see also Audio Frequencies).

NOTE: It is not implied that radiation cannot be secured at lower frequencies and the distinction from audio frequencies is merely one of definition based on convenience.

1020 **Resonance to an Exciting Alternating Current** of a given frequency in an oscillating circuit is that condition in which the resulting effective current (or voltage) in that circuit is a maximum.

If neither the free nor the forced alternating currents of the driven circuit are highly damped, then resonance is obtained when the frequency of the free alternating current is approximately equal to the frequency of the forced alternating current.

That is, $$\omega = \frac{1}{\sqrt{LC}} = \omega_1$$

Where: ω = $2\pi \times$ the frequency of the free alternating current in the circuit.
L = the effective inductance of the circuit.
C = the effective capacity of the circuit.
ω_1 = angular velocity of the forced alternating current.

This is equivalent to the condition $\omega L = \frac{1}{\omega C}$ *i.e.*, the inductive reactance at that frequency is numerically equal to the capacitive reactance, or that the total reactance $\left(\omega L - \frac{1}{\omega C}\right)$ is equal to 0.

1021 **A Resonance Curve** gives the power, current, or voltage at various frequencies of excitation, as a function of those frequencies. or of the corresponding wave lengths.

1022 **A Wave-Length Resonance Curve** is one wherein the abscissas are ratios of specified wave lengths to the resonant wave length, and the ordinates are ratios of the energy (or square of the current) at corresponding specified wave lengths to the energy (or square of the current) at the resonant wave length. It is advantageous to have the scales of ordinates and abscissas equal.

1023 **A Frequency Resonance Curve.** One wherein the abscissas are ratios of specified frequencies to the resonant frequency, and the ordinates are ratios of the energy (or square of the current) at corresponding specified frequencies to the energy (or square of the current) at the resonant frequency. The scales of ordinates and abscissas are equal.

1024 **A Standard Resonance Curve,** unless otherwise specified, is assumed to be a wave-length resonance curve.

1025 **Selecting.** The process of adjusting an element driven by a plurality of simultaneous impulses, until the ratio of desired response to undesired response is a maximum.

1026 **Sustained Radiation** consists of electromagnetic waves of constant amplitude (such as are emitted from an antenna in which a forced alternating current flows.)

1027 **Tuning.** The process of securing the maximum indications by adjusting the time period of a driven element. (In transmitter or receiver.)

1028 **A Wave-Length Meter,** commonly called a **Wave-Meter,** is a radio frequency measuring instrument, calibrated to read wave lengths.

1029 **Rating.** 1. All radio transmitting sets shall be rated in actual power output measured in the antenna.

NOTE: The group or audio frequency of the note of the station should be stated as well, (except for sustained wave sets, where that characteristic should be mentioned).

2. The over-all efficiency of a radio transmitting station shall be the ratio of the actual power output as measured in the antenna to the power input supplied to the first piece of electrical machinery which is definitely a part of the radio equipment.

1030 **Decremeter.** An instrument for measuring the logarithmic decrement of a circuit or of a train of electromagnetic waves.

1031 **Attenuation, Radio.** The decrease with distance from the radiating source, of the amplitude of the electric and magnetic forces accompanying (and constituting) an electromagnetic wave.

1032 **Attenuation Coefficient (Radio).** The coefficient, which, when multiplied by the distance of transmission through a uniform medium, gives the natural logarithm of the ratio of the amplitude of the electric or magnetic forces at that distance, to the initial value of the corresponding quantities.

1033 **Coupler.** An apparatus which is used to transfer radio-frequency energy from one circuit to another by associating portions of these circuits.

APPENDIX II.

ADDITIONAL STANDARDS FOR RAILWAY MOTORS

1100 In comparing projected motors, and in case it is not possible or desirable to make tests to determine mechanical losses, the following values of these losses, determined from the averages of many tests over a wide range of sizes of single-reduction single-geared motors, will be found useful, as approximations. They include axle-bearing, gear, armature-bearing, brush-friction, windage, and stray-load losses.

TABLE XX

Approximate Losses in D-C. Railway Motors.

Input in per cent of that at nominal rating	Losses as per cent of input
100 or over	5.0
75	5.0
60	5.3
50	6.5
40	8.8
30	13.3
25	17.0

1101 The core loss of railway motors is sometimes determined by separately exciting the field, and driving the armature of the motor to be tested, by a separate motor having known losses and noting the differences in losses between driving the motor light at various speeds and driving it with various field excitations.

1102 **Selection of Motor For Specified Service**

The following information relative to the service to be performed, is required, in order that an appropriate motor may be selected.

(a) Weight of total number of cars in train (in tons of 2000 lb.) exclusive of electrical equipment and load.

(b) Average weight of load and durations of same, and maximum weight of load and durations of same.

(c) Number of motor cars or locomotives in train, and number of trailer cars in train.

(d) Diameter of driving wheels.

(e) Weight on driving wheels, exclusive of electrical equipment.

(f) Number of motors per motor car.

(g) Voltage at train with power on the motors—average, maximum and minimum.

(h) Rate of acceleration in mi. per. hr. per second.
(i) Rate of braking (retardation in m. per hr. per second).
(j) Speed limitations, if any (including slowdowns).
(k) Distances between stations.
(l) Duration of station stops.
(m) Schedule speed including station stops in m.p.h.
(n) Train resistance in pounds per ton of 2000 pounds at stated speeds.
(o) Moment of inertia of revolving parts, exclusive of electrical equipment.
(p) Profile and alignment of track.
(q) Distance coasted as a per cent of the distance between station stops.
(r) Time of layover at end of run, if any.

1103 **Stand-Test Method of Comparing Motor Capacity with Service Requirements:** When it is not convenient to test motors under actual specific service conditions, recourse may be had to the following method of determining temperature rise.

1104 The essential motor losses affecting temperatures in service are those in the motor windings, core and commutator. The mean service conditions may be expressed, as a close approximation, in terms of that continuous current and core loss which will produce the same losses and distribution of losses as the average in service.

A stand test with the current and voltage which will give losses equal to those in service, will determine whether the motor has sufficient capacity to meet the service requirements. In service, the temperature rise of an enclosed motor (**§164**), well exposed to the draught of air incident to a moving car or locomotive, will be from 75 to 90 per cent (depending upon the character of the service) of the temperature rise obtained on a stand test with the motor completely enclosed and with the same losses. With a ventilated motor (**§165** and **§167**), the temperature rise in service will be 90 to 100 per cent of the temperature rise obtained on a stand test with the same losses.

1105 In making a stand test to determine the temperature rise in a specific service, it is essential in the case of a self-ventilated motor (**§ 167**), to run the armature at a speed which corresponds to the schedule speed in service. In order to obtain this speed it may be necessary, while maintaining the same total armature losses, to change somewhat the ratio between the I^2R and core-loss components.

1106 **Calculation for Comparing Motor Capacity with Service Requirements.** The heating of a motor should be determined, wherever possible, by testing it in service, or with an equivalent duty cycle. When the service or equivalent duty-cycle tests are not practicable, the ratings of the motor may be utilized as follows to determine its temperature rise.

1107 The motor losses which affect the heating of the windings are as stated above, those in the windings and in the core. The former are proportional to the square of the current. The latter vary with the voltage and current, according to curves which can be supplied by the manufacturers. The procedure is therefore as follows:

1108 (a) Plot a time-current curve, a time-voltage curve, and a time-core loss curve for the duty cycle which the motor is to perform, and calculate from these the root-mean-square current and the equivalent voltage which, with this r.m.s. current, will produce the average core loss.

1109 (b) If the calculated r.m.s. service current exceeds the continuous rating, when run with average service core loss and speed, the motor is not sufficiently powerful for the duty cycle contemplated.

1110 (c) If the calculated r.m.s. service current does not exceed the continuous rating, when run with average service core loss and speed, the motor is ordinarily suitable for the service. In some cases, however, it may not have sufficient thermal capacity to avoid excessive temperature rises during the periods of heavy load. In such cases a further calculation is required, the first step of which is to calculate the temperature rise due to the r.m.s. service current, and equivalent voltage.

$$\text{Let}\quad \left.\begin{array}{l} t = \text{temperature rise} \\ p_0 = I^2R \text{ loss, kw.} \\ p_c = \text{core loss, kw.} \end{array}\right\} \begin{array}{l}\text{with r.m.s. service current, and equiva-} \\ \text{lent service voltage.}\end{array}$$

$$\left.\begin{array}{l} T = \text{temperature rise} \\ P_0 = I^2R \text{ loss, kw.} \\ P_c = \text{core loss, kw.} \end{array}\right\} \begin{array}{l}\text{with continuous load current correspond-} \\ \text{ing to the equivalent service voltage.}\end{array}$$

Then

$$t = T\,\frac{p_0 + p_c}{P_0 + P_c}, \text{ approximately.}$$

1111 (d) The thermal capacity of a motor is approximately measured by the ratio of the electrical loss in kw. at its nominal (one-hour) capacity, to the corresponding maximum observable temperature rise during a one hour test starting at ambient temperature.

1112 (e) Consider any period of peak load and determine the electrical losses in kilowatt-hours during that period from the *electrical* efficiency curve. Find the excess of the above losses over the losses with r.m.s. service current and equivalent voltage. The excess loss, divided by the co-efficient of thermal capacity, will equal the extra temperature rise due to the peak load. This temperature rise added to that due to the r.m.s. service current, and equivalent voltage, gives the total temperature rise. If the total temperature rise in any such period exceeds the safe limit, the motor is not sufficiently powerful for the service.

1113 (f) If the temperature reached, due to the peak loads, does not exceed the safe limit, the motor may yet be unsuitable for the service, as the peak loads may cause excessive sparking and dangerous mechanical stresses. It is, therefore, necessary to compare the peak loads with the short-period overload capacity. If the peaks are also within the capacity of the motor, it may be considered suitable for the given duty cycle.

APPENDIX III.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

REPORT OF THE BOARD OF DIRECTORS FOR FISCAL YEAR ENDING APRIL 30, 1914

The Board of Directors of the American Institute of Electrical Engineers presents herewith to the membership its annual report for the fiscal year ending April 30, 1914.

Only a summary of the work which has been accomplished during the year is possible in this report, but in the preparation of it a sufficient amount of detail has been given to convey a general idea of the scope and activity of the Institute. Those members desiring further information are referred to past issues of the monthly PROCEEDINGS, in which nearly all matters of importance have been given publicity in greater detail. Abstracts of the reports of many of the Institute committees, as submitted to the Board, are included herein.

The exact status of the Institute's financial affairs will be found in the statements at the end of this report, which show the finances to be in sound and satisfactory condition. The statements also contain detailed information respecting the various trust funds, assets and liabilities, and other financial data.

Meetings of the Board.—The Board of Directors has held 10 meeting during the year; nine at Institute headquarters in New York, and one at Cooperstown, N. Y., during the Annual Convention. In order that the membership may keep closely in touch with the administration of the Institute's affairs, a résumé of business transacted at these meetings is published each month in the Institute PROCEEDINGS. This, however, represents only a portion of the business transacted by the Board, as many important matters are considered to which publicity is not given pending their final settlement. Such matters are dealt with in subsequent issues of the PROCEEDINGS under appropriate headings.

Conventions.—The Annual Convention was held in Cooperstown, N. Y. June 23–27, 1913. The total registered attendance was 242, of which 171 were Institute members. Of the 71 guests, 54 were ladies. Twenty-four papers were presented at the six technical sessions. The reduction in the number of papers over the two previous years was favorably commented upon, as it afforded longer time for discussion and eliminated the necessity for parallel sessions.

The success of the first Midwinter Convention, held in New York early in 1913, led the Board to give favorable consideration to a demand for a similar convention this year, which was held at Institute headquarters February 25–27, 1914, under the auspices of the Electric Power Committee. Sixteen papers and reports on the general subject of electric power were presented, several of the reports embodying separate short papers by different authors, each devoted to some subdivision of the main subject. The total registered attendance was 472, of which 354 were Institute members. A subscription dinner-dance, under the joint auspices of the Institute and the Executive Committee of the Committee on Organization of the International Electrical Congress to be held in San Francisco in 1915, was the only official social function of the convention. About 350 members and guests participated in this event.

The fifth annual Pacific Coast Convention was held in Vancouver, B. C., September 9–11. The arrangements were made and admirably carried out under the auspices of the Vancouver Section. Six technical papers, relating chiefly to industries and operations of interest to engineers on the coast and in the northwest, were presented. The total attendance was 154. Vice-President Lighthipe represented the President, and presided at this meeting.

Other Meetings.—A meeting was held in Philadelphia, Pa., on October 13, 1913, under the auspices of the Philadelphia Section. Three papers were presented and discussed at this meeting, and the total attendance was 204.

A meeting was held in Pittsburgh, Pa., April 9–10, 1914, under the auspices of the Committee on the Use of Electricity in Mines and the Pittsburgh Section. Five papers on the application of electricity in mining were presented, and 191 members and guests attended.

A two-day meeting was held in Washington, D. C., April 24–25, 1914, in cooperation with the American Physical Society. The meeting was conducted on behalf of the Institute by the Electrophysics Committee, with the assistance of the Washington and Baltimore Sections, and the papers presented related more or less to the general subject of electrophysics. The Institute contributed five of the papers presented at the meeting.

In addition to the foregoing meetings, regular monthly meetings have also been held in New York, excepting during the summer months.

The Sections and Branches of the Institute have been exceedingly active, having held more than 500 meetings throughout the country.

During the year, President Mailloux, Honorary Secretary Pope, and Secretary Hutchinson have attended a large number of Institute and Section meetings in various parts of the country.

Future Institute meetings during the present year are being arranged for, as follows: Pittsfield, Mass., May 28–29; Annual Convention, Detroit, Mich., June 23–26, Pacific Coast Convention, Spokane, Wash., September 9–11.

Scientific Lectures.—The wide-spread interest shown by members and non-members in the lectures on radioactivity by Professor E. P. Adams of Princeton University a year ago prompted the Board to authorize the appointment of a special committee on Technical Lectures last fall, through which arrangements were made with Dr. M. I. Pupin, Professor of Electromechanics in Columbia University, New York, to deliver two lectures on the subject of the relation of the electromagnetic theory to the science of electrical engineering of the present day. The lectures were given in New York on April 29 and May 6, 1914. Dr. Pupin's lectures were planned to bring out the points of contact between Maxwell's electromagnetic theory and the ordinary and less broad electromagnetic theory which serves as the foundation of electrical engineering today.

International Electrical Congress.—The Executive Committee of the Committee on Organization of the International Electrical Congress, San Francisco, 1915, which is invested with powers to carry on the work for the general committee, was reorganized during the year with a chairman, a vice-chairman, and nine other members, in order that it could more effectively carry on its work, which has developed considerably during the year. The question of financing the Congress was referred to the Board of Directors for consideration by the committee last fall, and it became necessary to make some adequate provision for funds to be available for this purpose until such time as the committee's income through subscriptions would enable it to finance the Congress independently of the Institute. This was accomplished by the passage of a resolution by which the Institute agreed to underwrite the expenses of the Congress to the extent of $15,000, with the understanding that the Institute is to be reimbursed to the full amount advanced if the Congress proves to be self-supporting, as expected, and is to receive the profits, if any. In agreeing to underwrite the expenses of the Congress, the Board took the view that inasmuch as the project of holding the Congress originated with the Institute, and as, by authority of the International Electrotechnical Commission, the Congress is being conducted under the auspices of the Institute, the responsibility for obligations incurred in connection with it rests upon the Institute. Additional information regarding the Congress may be found in the abstract of the report of the Executive Committee in the following pages.

International Engineering Congress.—This congress is entirely distinct from the Electrical Congress, and is to be held a week after the latter. It is being organized under the auspices of the American Society of Civil Engineers, the American Society of Mechanical Engineers, the American Institute of Mining Engineers, the Society of Naval Architects and Marine Engineers, and the American Institute of Electrical Engineers. The Institute's interest in this congress is limited, on account of its obligations to the Electrical Congress, for which it is solely responsible, and upon the success of which its efforts must necessarily be largely centered. The Institute is, however, heartily in sympathy with the proposed engineering congress, is represented upon its Board of Management, and is actively cooperating in the work of preparation.

Standardization Rules.—One of the most useful and important activities which the Institute has undertaken in recent years, and upon which a very large amount of time and energy has been concentrated during the past year, is the preparation of a revised edition of the Standardization Rules. Credit for this work is due to the Standards Committee, which, after nearly two years of unremitting labor, has practically completed the revision of the rules, and it is expected that the revised rules will be referred to the Board of Directors for formal action at the coming Annual Convention.

Foreign Relations.—The Institute's relations with foreign engineering societies have continued harmonious and cordial. The reciprocal arrangement for the exchange of visiting member privileges with some of the foreign societies still remains in force, and has been availed of to a considerable extent. The Secretary has issued during the past year a large number of visiting member certificates to Institute members who have gone abroad, and an approximately equal number of certificates from foreign societies has been honored by the Institute.

An important step towards international representation was taken by President Mailloux last August by the appointment, upon authorization of the Board, of representatives of the Institute upon the United States National Committee of the International Illumination Commission, a newly-organized body formed from the International Photometric Commission at a meeting of the latter held for that purpose in Berlin, in August, 1913. In all, ten countries were represented by delegates. President Mailloux unofficially represented the Institute and took a conspicuous part in the proceedings. All of the statutes, resolutions and official documents of the Commission are to be drawn up in the French language, while the national committees may draw up translations which may be published on their own respective responsibilities. Several other American organizations are represented on the U. S. National Committee.

The very friendly relations which have always existed between the American Institute of Electrical Engineers and the Institution of Electrical Engineers of Great Britain have become more cordial than ever during the last year, through the personal efforts of their presidents, prior to and since their meeting at Berlin in August, 1913, as members of the official delegations from their respective countries to the meetings of the International Illumination Commission and of the International Electrotechnical Commission.

In accordance with arrangements previously made by letter and by cable a special conference of prominent members of the A. I. E. E. and the I. E. E. took place at London, in August, 1913, prior to the Berlin meetings. The purpose of this conference was to exchange and compare views, adjust and reconcile policies and programmes, and, in general, to secure coöperative, concerted action between the two countries in regard to electrical standardization and various cognate matters, and on questions of mutual interest to both. This conference was most effective in promoting good feeling, and in stimulating the desire for coöperation between the two bodies. It paved the way for an "*entente cordiale*" which, a few days later, at Berlin, produced telling results, by making the representatives from England and the United States work together in most satisfactory and effective manner, their joint efforts and influence having proved quite preponderating both in the organization of the I. I. C. and in the meetings of the I. E. C.

The desire for continued and systematic coöperation between the A. I. E. E. and the I. E. E. having already found expression at London and at Berlin, and the advantages thereof having become manifest since then, the matter was studied further on both sides and arrangements satisfactory to both sides were agreed upon. Formal action in carrying out these arrangements was taken by President Mailloux last February, when he obtained the authority of the Board to suggest to the Institution of Electrical Engineers that a Joint Conference Committee composed of representatives of the Institution and the Institute be organized to deal with matters regarding which concerted action between the standards committees of the two bodies might be desirable, and, if the suggestion was received favorably, to appoint the Institute's representatives. The Institution promptly accepted the invitation of the Institute to participate in the formation of such a joint committee.

Committees and Departments.—Upon entering into his administration of the Institute's affairs in August, 1913, President Mailloux, with the sanction of the Board, reorganized the technical committees and divided the work of the Institute into six departments, with a vice-president and manager at the head of each department as Councillor and Vice-Councillor. The features of the plan were fully described in the September, 1913, PROCEEDINGS.

The Standards Committee was considerably enlarged so as to permit the appointment of sub-committees of a suitable number.

Three new committees were appointed; namely, Electric Power, Electrically Propelled Vehicles, and Prime Movers. The Electric Power Committee was organized to cover a very broad field, and was divided into sub-committees on Power Stations, Power Generation, Protective Apparatus, Transmission, Distribution, Economics, and Engineering Data, each sub-committee having its own chairman and membership.

Committee Reports.—The following abstracts of the reports submitted by the chairmen of various permanent Institute committees give an outline of the activities of these committees. Much important work has also been accomplished by temporary committees appointed during the year for specific purposes; also by delegates of the Institute to meetings of other technical organizations and by representatives upon various boards, commissions, and other local and national bodies.

Sections Committee.—In accordance with the custom of previous years, the activities of the various Sections and Branches of the Institute are shown briefly in tabular form below:

	Year Ending						
	May 1 1908	May 1 1909	May 1 1910	May 1 1911	May 1 1912	May 1 1913	May 1 1914
Sections							
Number of Sections	21	24	25	25	28	29	30
Number of Section meetings held....	141	169	187	208	231	244	233
Total attendance...	7476	16,427	16,604	15,243	19,800	22,825	22,626
Branches							
Number of Branches	22	26	31	36	42	47	47
Number of Branch meetings held.....	143	198	237	255	281	357	306
Attendance.........	4128	8,443	10,255	10,714	10,255	11,808	11,617

One new Section has been formed within the last year, at Panama. Judging from the notices that have come from the new Section, it has had a highly successful inauguration.

The Pacific Coast membership have not as yet held their annual convention, but it is held over until September, thereby making it the first of the Institute meetings which will occur in the next administrative year. This will be the sixth of these Pacific Coast conventions which have been held among the six Pacific Coast Sections. The convention this year will be held in Spokane, Wash., September 9, 10 and 11.

These conventions have been highly influential in maintaining the solidarity of the Institute membership on the Pacific Coast.

The Sections and Branches continue to maintain the important place in Institute activities that they have maintained since their inauguration twelve years ago.

Meetings and Papers Committee.—The Meetings and Papers Committee has had general supervision of the arrangements for the Institute meetings and conventions held throughout the country during the year. In providing the program for these meetings the committee has had the coöperation and assistance of various other Institute committees. The chairman of the committee contributing the paper for discussion at a meeting has usually presided at the technical session at that meeting.

The committee is now making preparation for the Annual Convention, which is to be held in Detroit, Mich., June 23-26, 1914. The committee is pursuing the same policy as last year in limiting the number of papers to be presented, having found this a great advantage, as it affords a longer time for discussion and eliminates the necessity for parallel sessions.

New York Reception Committee.—The New York Reception Committee has arranged for the smokers which have been held at Institute headquarters in connection with the monthly meetings. These smokers have been supported entirely by voluntary contributions from members residing in and near New York.

Standards Committee.—The membership of the Standards Committee, as appointed last year, has been larger than heretofore, so as to permit of the division of the committee into sub-committees on specific subjects. Six sub-committees have been created, to deal with the subjects of Rating, Telegraph and Telephone Standards, Railroad Standards, Nomenclature and Symbols, Cables, and Rating and Testing of Control Apparatus. Each sub-committee has been presided over by a chairman.

The committee, as a whole, has bent its energies during the year to producing a new edition of the Standardization Rules. Since the last edition was issued in 1911 many rules in it have ceased to be useful, and should be superseded. A large amount of material for the new edition was laid before the Institute in the papers read at the New York Midwinter Convention of February, 1913. Since that date the Standards Committee has been actively engaged in drawing up the proposed new rules and in circulating the proposals for discussion. Preliminary drafts of sections of the proposed new rules were printed in December, 1913, January, February, March and April, 1914. Many of these drafts have been extensively circulated, especially those prepared by the sub-committee on Rating. The sub-committees have successively discussed and modified these drafts in local meetings attended by specialists from different parts of the country.

The meeting of the whole committee in April, at the Institute rooms, lasted two full days. The latest revision is now being prepared for further distribution, and for final discussion at a meeting in June. It is expected that the committee will then be able to submit the new edition to the Board of Directors at the Annual Convention.

Code Committee.—The Code Committee was represented by its chairman at a Conference on Fire Prevention held in Philadelphia in October, 1913, under the auspices of the Philadelphia Fire Prevention Commission. The outcome of the conference was that the work which it was expected would be handled by the Commission is to be taken care of by the Public Policy Committee of the National Board of Fire Underwriters.

The chairman of the committee also represented the Institute at the biennial meeting of the Electrical Committee of the National Board of Fire Underwriters held in Boston in April. At this meeting the committee appointed to reconstruct Rule 13, dealing with outside construction, decided to postpone definite action until the result of the work of the joint committee of the American Railway Association on the joint use of poles is known.

Library Committee.—In accordance with Section 24 of the by-laws of the Institute, the Library Committee begs leave to submit herewith its report for the fiscal year ending April 30, 1914, showing the general condition of the library, and including the names of all donors to it.

The administration of the library's affairs by the Library Board, which was organized for this purpose with the approval of the founder societies in February 1913, has proved very satisfactory, and the Board has accomplished a considerable amount of constructive work during the year.

One of the most important matters to claim the attention of the Board was the general question of financing the library. The subject was brought up for discussion at a meeting held on December 4, 1913, and resulted in the appointment of a special committee consisting of the secretaries of the three founder societies to formulate a plan for the apportionment of expenditures and appropriations for the library, and to make specific recommendations for the classification of library accounts.

This committee submitted its report to the Library Board on February 5, 1914, and on March 26, 1914, the plan recommended by the committee was formally adopted by the Board of Trustees of the United Engineering Society. The principal features of the plan are as follows:

1. That a permanent Finance Committee of three members of the Library Board, one representative from each society, be created, each member being designated by the Library Committee of the society which he represents. This committee to have supervision of the library expenditures under the direction of the Library Board.

2. That the United Engineering Society bear one-quarter of the operating expenses of the library, dating from January 1, 1914, the remaining three-quarters to be borne equally by the three founder societies.

3. That all purchases of books, periodicals and binding be made by the librarian upon the authorization of the Library Committee of the founder society concerned, or in the case of the United Engineering Society, by the Finance Committee of the Library Board, and that the

cost of such books, periodicals and binding be borne in each case by the society concerned.

4. That the research work carried on under the direction of the librarian be made, as far as possible, self-supporting.

Under this plan the United Engineering Society shares in the operating expenses of the library, which heretofore were borne entirely by the three founder societies.

The library now contains over 54,000 volumes, and about 1,600 complete and partial sets of periodicals. Over 800 periodicals are received currently.

Data, which shall form the basis of a list of the sets of technical periodicals in the various libraries of New York City, have been obtained and the work of compiling this list is now progressing.

The research department has developed considerably during the year. Over a thousand questions have been received requiring research, and a large number of photographic reproductions and reference lists have been sent to out-of-town clients, both here and abroad, thus extending the facilities of the library to every part of the world. The fees for research work have been slightly increased, with a view to making this department self-supporting.

Statistical information concerning the library and its use during the year, including a list of donors, is given in the following tables.

DONORS
May 1, 1913—April 30, 1914

ADAMS, E. D.	6
AMERICAN ELECTRIC RAILWAY ASSOCIATION	14
AMERICAN ELECTROCHEMICAL SOCIETY	3
AMERICAN INSTITUTE OF CONSULTING ENGINEERS	1
AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS	1
AMERICAN MINING CONGRESS	1
AMERICAN RAILWAY ASSOCIATION	1
AMERICAN SCHOOL OF CORRESPONDENCE	2
AMERICAN TELEPHONE AND TELEGRAPH COMPANY	4
ARGENTINE SOCIAL MUSEUM	1
ARNOLD, B. J.	6
ASSOCIATION OF IRON AND STEEL ELECTRICAL ENGINEERS	1
BARBIERI, M.	1
BISHOP, L. W.	1
BRAMMER, J. C.	1
BROOKLYN ENGINEERS CLUB	1
CALDWELL, EDWARD	2
CARNEGIE LIBRARY OF PITTSBURGH	1
CHICAGO COMMITTEE ON GAS, OIL AND ELECTRIC LIGHT	1
CITY AND GUILDS ENGINEERING COLLEGE	1
CLEVELAND ENGINEERING SOCIETY	1
CONGRESO CIENTIFICO (1° PAN AMERICANO)	2
CONGRESSO INTERNAZIONALE DELLE APPLICAZION. ELETTRICHE	1
CROCKER, FRANCIS B.	5
DELAWARE COLLEGE	1

DEPARTMENT OF TERRESTRIAL MAGNETISM	1
ELECTRIC RAILWAY JOURNAL	1
ELECTRICAL WORLD	1
ELECTRO-TECHNICAL LABORATORY, TOKYO	2
ELECTRO-TECHNICAL LABORATORY, DEPT. OF COMMUNICATION, TOKYO	2
ENGINEERS' CLUB OF PHILADELPHIA	1
FORD, BACON & DAVIS	1
FOWLE, F. F	2
FOWLER, C. P	1
FRANKLIN INSTITUTE	1
GENERAL RAILWAY SIGNAL COMPANY	1
GAUTHIER-VILLARS	2
HAMMER, WILLIAM J	1
HERMANN ET FILS	2
HUTCHINSON, F. L	1
ILLUMINATING ENGINEERING SOCIETY	1
INSURANCE SOCIETY OF NEW YORK	1
IOWA ENGINEERING SOCIETY	1
JANECKE	1
JONES, R. M	1
JOSEPH DIXON CRUCIBLE COMPANY	1
KANSAS ENGINEERING SOCIETY	1
KENNELLY, A. E.	4
KIRCHGASSER	1
KNOWLES, EDWARD R	57
KOWALEUKOFF, W	3
LLOYD'S REGISTER OF SHIPPING	1
LOS ANGELES EXAMINER	1
LUDIN, ADOLF	2
LUMIERE ELECTRIQUE	1
MARYLAND PUBLIC SERVICE COMMISSION	1
MASSACHUSETTS BOARD OF GAS AND ELECTRIC LIGHT COMMISSIONERS	1
MASSACHUSETTS INSTITUTE OF TECHNOLOGY	1
MAYER, WM	6
MINISTERIO DA VIAGAS E OBRAS PUBLICAS, BRAZIL	2
MINISTERO DELLE POSTE E DEI TELEGRAFI	1
MUNICIPAL ENGINEERS OF THE CITY OF NEW YORK	1
NATIONAL ELECTRIC LIGHT ASSOCIATION	1
" " " " BOSTON SECTION	1
NATIONAL FIRE PROTECTION ASSOCIATION	5
NEW ORLEANS SEWERAGE AND WATER BOARD	1
NEW YORK (CITY) BOARD OF TRADE	1
NEW YORK (CITY) BOARD OF WATER SUPPLY	3
NEW YORK (CITY) DEPARTMENT OF WATER SUPPLY, GAS AND ELECTRICITY	1
NEW YORK (STATE) DEPARTMENT OF LABOR	4
NEW YORK (STATE) PUBLIC SERVICE COMMISSION	1
NORSA, RENZI	1

OESTERREICHISCHER INGENIEUR UND ARCHITEKTENVEREIN	2
PENROSE, CHARLES	1
PIERCE, A. L.	2
POLYTECHNIC INSTITUTE OF BROOKLYN	4
PREFECTURE DE LA SEINE	1
PULLIGNY, L. DE	1
REED, HENRY D.	1
SAINZ, J.	1
SCHOOL OF ENGINEERING OF MILWAUKEE	1
SIMON, ARTHUR	1
SOCIETY FOR THE PROMOTION OF ENGINEERING EDUCATION	1
SOCIETY OF CHEMICAL INDUSTRY	1
SOUTHWESTERN ELECTRICAL AND GAS ASSOCIATION	2
STREET RAILWAY ASSOCIATION OF THE STATE OF NEW YORK	1
TELEPHONE PIONEERS OF AMERICA	1
THOMPSON, S.	1
ULISSE DEL UNONO	1
UNDERWRITERS LABORATORIES, INC.	1
U. S. BUREAU OF NAVIGATION, DEPT. OF COMMERCE	1
U. S. BUREAU OF STANDARDS	1
U. S. DEPARTMENT OF AGRICULTURE	4
U. S. WAR DEPARTMENT	1
D. VAN NOSTRAND COMPANY	4
VERBAND DEUTSCHER ELEKTROTECHNIKER	1
WEAVER FUND	1
WEIN, SAMUEL	1
WESTERN UNION TELEGRAPH COMPANY	1
WOODBURY, C. J. H.	1

SUMMARY OF ACCESSIONS

May 1, 1913—April 30, 1914

Donors	185
Exchange	170
Purchase and old material	122
Total accessions	477

STATISTICS OF LIBRARY MAY 1, 1914

Source	Vols.	Pamphlets	Valuation
Report of May 1, 1913	16,843	1652	$34,432.75
Purchase	109	1	218.25
Gifts and exchanges	318	37	645.25
Old material accessioned	12		24.00
	17,282	1690	$35,320.25

LIBRARY ATTENDANCE

		Day	Night	Total
May	1913	793	213	1,006
June	"	579	142	721
July	"	652	closed	652
August	"	612	79	691
September	"	715	197	912
October	"	894	212	1,106
November	"	850	235	1,091
December	"	1,037	286	1,323
January	1914	1,115	302	1,417
February	"	949	293	1,242
March	"	984	339	1,323
April	"	936	309	1,245
Total May 1913-April 1914		10,122	2607	12,729
Total May 1912-April 1913		7,667	2280	9,947

In the following table are given figures for the total valuation of the library property, no allowance having been made for depreciation:

Books	$35,320.25
Stacks	1,761.05
Furniture, catalogue cases, etc.	376.00
Wheeler cases	930.00
	$38,387.30

The following tabulation gives the state of the accounts from which the Library Committee is entitled to draw:

MAILLOUX ENDOWMENT FUND ($1,000)

(Proceeds for the maintenance of specific sets of periodical publications).

Balance May 1, 1913	$77.55	Expended	$26.75
Interest	45.00	Unexpended	95.80
	$122.55		$122.55

INTERNATIONAL ELECTRICAL CONGRESS OF ST. LOUIS, 1904, FUND.

(Proceeds available for the purchase of non-American international electrical literature).

Invested in New York City 4½% Bonds	$2268.00
Additions to the Funds	81.00
Total Fund	$2349.00

Balance on hand May 1, 1913	$395.24	Expended	0.00
Interest	90.00	Unexpended	485.24
	$485.24		$485.24

During the year the General Library Fund, amounting to $284.92, and the Weaver Fund, amounting to $6.69, were expended for the purchase of books for the library, and therefore these two accounts do not appear in the statement given above, nor are these amounts included in the record of expenses given below.

INSTITUTE EXPENSES ON ACCOUNT OF LIBRARY.

Share of salaries of librarian, assistants, cataloguer and desk attendant (one-third from May 1, 1913 to December 31, 1913, and one-fourth for remainder of year ending May 1, 1914)	$2600.40
Share of library's supplies, etc.	137.02
*Books and periodicals	150.18
Insurance	88.21
Binding	334.85
	$3310.66

Respectfully submitted,
F. L. HUTCHINSON
F. B. JEWETT
MALCOLM MACLAREN
W. I. SLICHTER
SAMUEL SHELDON, *Chairman.*

Railway Committee.—The Railway Committee has endeavored to make progress in getting comparisons of actual equipment and operating costs characteristic of the various direct-current and single-phase electrical installations connected with trunk line traffic, but thus far has been unsuccessful, because, while some of the officials concerned have been willing to make the necessary exhibits, they have found themselves unable to do so without the coöperation of all concerned. Efforts to this end have therefore been deferred for the present.

Electric Illumination Committee.—This committee was not appointed until November last, by which time the Institute's work for the administrative year was well under way. The committee has held one meeting and has had considerable correspondence, including negotiations with the Illuminating Engineering Society with regard to joint work and obtaining papers on the subject of illumination for the Annual Convention and later meetings of the Institute.

Electric Power Committee.—The Electric Power Committee has been principally engaged with the formation of its plans for the development and holding of the Midwinter Convention. It is anticipated that during the remainder of the year an outline will be prepared of the standardization work which can be desirably handled by the committee and of the specifications which may be outlined by it. Preparations are also being made to take care of one session of the Annual Convention in Detroit.

The activities of the sub-committees on Power Stations, Power Generation, Transmission, Distribution, Economics and Engineering Data are covered in the following abstracts.

Power Stations Sub-Committee.—The Power Stations Committee held many meetings in Boston, which were generally limited to those members residing in Boston and its vicinity, and it also had considerable correspondence with distant members, with the object in view of outlining the duties of the committee and carrying them out efficiently. The committee took the responsibility for one of the sessions of the Midwinter Convention in New York in February, and provided papers for that session.

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*To obtain the total expenditures for books for the year, the amounts expended from the General Library Fund and the Weaver Fund should be added to this sum, thus making the total expenditures for books $441.79.

Power Generation Sub-Committee.—Under the auspices of this committee there was presented at the Midwinter Convention in New York a paper by Dr. Cary T. Hutchinson, on *The Economical Capacity of a Combined Hydroelectric and Steam Plant.*

Transmission Sub-Committee.—The Transmission Committee provided the papers for one of the sessions at the Midwinter Convention in New York in February. The principal paper consisted of a general report comprising data and records of experience contributed by the various members of the committee. Appended to the report were four short articles all relating to the general subject of transmission.

Distribution Sub-Committee.—The Distribution Committee prepared a report with nine appendixes, each covering a specific branch of electrical distribution. The report proper referred to some of the newer and larger general problems and the tendencies in generalized distribution. The report and appendixes, covering practically the entire field of electrical distribution, were presented and discussed at the Midwinter Convention.

Economics Sub-Committee.—The Economics Committee has concentrated its energies upon an effort to arrive at a proper method for recording power costs. The object to be attained is to record these costs so that the results will permit a true comparison of stations operating under different circumstances.

Engineering Data Sub-Committee.—The Engineering Data Committee, in cooperation with the Handbook Committee and the Electric Power Committee, provided the program for one session at the recent Midwinter Convention. The committee has in hand, and now has revised and ready for approval, the model or skeleton high-tension insulator testing specification which was prepared last year by the High-Tension Transmission Committee. It is believed that this specification will be found of considerable value in an educational way and in the establishment of uniformity in practise in insulator tests. The committee has also been continuing the collection of data on high-tension plants which was initiated last year, and now has in hand reports from some 20 companies, most of them containing valuable material. These are being analyzed and it is expected that the analysis will be completed for the Annual Convention. The committee is also trying out the plan of sending circular letters to a selected list of engineers asking for their experience or practise in regard to some particular question of engineering interest, usually at the request of some member wishing information on that particular topic. Such pertinent replies as are received are embodied in a circular letter and sent to the appropriate list of members.

Industrial Power Committee.—This committee was not appointed until late in October, at which time the schedule of regular meetings for the year had been practically decided upon. Consequently, the committee has concentrated its efforts towards arranging for papers to be presented at the Industrial Power session at the Annual Convention in Detroit in June. It is hoped that these plans will result in a satisfactory meeting. The committee expects to arrange an exhibit of moving pictures of the iron and steel industry for the Annual Convention.

Telegraphy and Telephony Committee.—The Telegraphy and Telephony Committee held no meetings during the year, owing to the wide geographical distribution of its membership. Under arrangements with the Meetings and Papers Committee it accepted the responsibility for the program of the Institute meeting held in New York on March 13, 1914. The Institute of Radio Engineers was invited to participate in this meeting. Three papers were presented; one dealing with railway telephone and telegraph practise, another with a study of telephone traffic in automatic systems, and the third with long-distance radio transmission.

The chairman had considerable correspondence with the members of the committee in regard to the collection and compilation of engineering data in the allied fields of telegraphy and telephony. A number of proposals were advanced by certain members of the committee, and these were submitted to the whole committee for discussion, but no decisive action resulted.

Electrochemical Committee.—The work of the Electrochemical Committee for the past year has been largely devoted to attempts to obtain suitable papers on electrochemistry treated from an engineering viewpoint. Owing to the scattered geographical distribution of its members it has been necessary to carry on the work through correspondence. Three papers were promised during the year, of which one will be presented at the Annual Convention. The remaining two papers are nearly completed and are definitely promised for next season and may be available in the fall.

The committee has also considered the question of collecting technical data in the electrochemical field with a view to collating this for publication under the auspices of the Institute, in line with similar work which is being carried on by several of the other technical committees. Many difficulties have been found in the way of this work, however, and no actual data were collected during the year. One feature that appears in the way of collecting engineering data relating to electrochemistry is the fact that some of the electrochemical industries have not been standardized to a sufficient extent to justify the standardization of the engineering data relating to these industries. Further, such data as the ordinary chemical and electrochemical constants would seem to be more properly collected in handbooks and textbooks, while new data of this kind would seem to be more properly collected by the Electrochemical Society. This society has a committee on electrochemical standards and units.

Electrophysics Committee.—The work of the Electrophysics Committee has been directed (1) to the securing of papers on subjects relating to the physical theory underlying electrical engineering, (2) to the stimulation of interest in experimental research, and (3) to the arrangement of a joint meeting of the Institute and the American Physical Society.

Up to the present time 10 papers have been considered. Five of these were presented at the Washington meeting, April 24 and 25, two are under consideration for the Annual Convention, and two have been rejected as unsuitable. Promises have also been received of two additional papers.

Through correspondence the committee has continued its efforts to secure a list of promising subjects for research. So far the results of this attempt have not been numerous, but it is hoped that by continued effort in this direction valuable material may eventually be collected.

The committee arranged the Institute meeting held in Washington April 24 and 25 in coöperation with the American Physical Society. The coöperation of the National Bureau of Standards and the Baltimore and Washington Sections was also secured. Arrangements were made for an interesting exhibit of measuring instruments and other apparatus relating to electrical engineering.

Committee on Use of Electricity in Mines.—During the past year the committee has given considerable attention to the question of regulations for electrical installations in mines. After a study had been made of the situation it was decided that it would be desirable to obtain a discussion of mining regulations from individuals interested in this work. There is no recognized standard for electrical work in mines, and on account of the increasing importance of this work it was considered that some standardization is desirable. A two-day meeting of the Institute was held in Pittsburgh on April 9 and 10, at which various European and American mining codes were discussed. In addition a number of papers were read which produced an interesting exchange of ideas. It was suggested that the subject of electrical installation in mines should receive attention from the committee for 1914-1915, with the object of obtaining joint action with other national societies toward the formation of a set of rules meeting with the approval of mining and electrical engineers, which could be used as a basis for standardization and future legislation by state governments.

Committee on Use of Electricity in Marine Work.—This committee has provided the two papers which will be presented at the New York meeting on May 19. These are, *Electricity the Future Power for Steering Vessels*, and *The Future of Electric Heating and Cooking in Marine Service.* The committee has held two meetings during the year and steps have been taken toward the formulation of rules covering electrical installations on shipboard, and the collection of data showing present good practise in marine installations.

Committee on Electrically Propelled Vehicles.—In view of the rapid growth in the use of electric vehicles for both pleasure and commercial purposes it appeared advisable to have an Institute Committee on Electrically Propelled Vehicles. The committee has held only one formal meeting, but the chairman has been in communication with the various members of the committee throughout the year. The general opinion of the members of the present committee is that the committee should confine its attention to the engineering features involved in the design and use of electric vehicles, and that questions of standardization of equipment and parts should be referred to the Standardization Committee of the Electric Vehicle Association of America.

At the request of the chairman of the Standardization Committee of the Electric Vehicle Association of America, the Committee on Electrically Propelled Vehicles has requested the Standards Committee of the Institute to approve the standard charging plug adopted by the Association, and has also requested the Standards Committee to endeavor to secure the adoption of this plug by the U. S. National Committee of the International Electrochemical Commission.

Committee on Records and Appraisals of Property.—This committee has decided that its efforts this year should be directed chiefly to formulating, as far as possible, a statement of the general principles which should underlie the production of correct appraisals and records of properties, and that it would be better not to attempt to lay more than a basic foundation upon which next year's committee can work.

Prime Movers Committee.—The Prime Movers Committee is now engaged on a report which it is hoped will be presented at the Annual Convention, covering the present status of the art of prime movers. This report will not only cover the relative efficiencies, but also the economics of the situation.

Educational Committee.—The Educational Committee planned to prepare a report dealing particularly with the development of more effective means of utilizing existing institutions for vocational training. The committee has been in correspondence with the secretaries of the Sections of the Institute, and individual members of the committee have under way special studies, all bearing on the same general subject. The report is nearing completion, but it will not be possible to present it at the Annual Convention as it was hoped could be done, and therefore it is now planned to refer it to next year's committee.

Committee on Technical Lectures.—In accordance with suggestions received at the time of its appointment, the Committee on Technical Lectures arranged for two lectures on the subject of "The Electromagnetic Theory and Its Relation to the Science of Electrical Engineering of the Present Time," by Dr. M. I. Pupin, Professor of Electromechanics at Columbia University. These lectures were given in New York on April 29 and May 6, and were largely attended by Institute members and others.

The committee has considered the subject of arranging for representatives of the Institute to deliver popular lectures on engineering subjects in coöperation with the boards of education of various cities. It is the sentiment of the committee that it is desirable that this work should be undertaken next year.

Editing Committee.—Twelve numbers of the PROCEEDINGS have been published under the auspices of the Editing Committee since April 30th, 1913; the total number of pages being practically the same as for the past two years. During the past year the committee adopted the policy of cutting down the discussions before sending the stenographer's reports to the various speakers for revision. By this means the length of discussion is indicated by the Editing Committee in advance, and considerable correspondence in regard to condensation of discussion has thereby been eliminated. This practise has apparently proved equally satisfactory to the authors and the Editing Committee. During the past year the separate pages for the titles and abstracts of papers in the PROCEEDINGS have been eliminated and the abstract included on the title page as part of the paper. The typographical style of the PROCEEDINGS has thereby been improved and a saving of over $1,000 effected by the elimination of two pages for each of the papers published. The change in the weight and character of the paper on which the 1912 issue of the TRANSACTIONS was printed permitted this volume to be issued in two parts instead of three as in the previous year, thereby effecting considerable saving in shelf space for the volume as well as a substantial saving in cost of publication.

Indexing Transactions Committee.—The Index to the TRANSACTIONS covering the period from 1884 to 1910 was completed last fall. Volume II, covering the years 1901 to 1910, was issued in September, and Volume I, covering the years 1884 to 1900, was issued a few months later. Announcements that the volumes were ready and would be sent gratis to any Institute member desiring them, were published in the September and December 1913 issues of the PROCEEDINGS, together with full information regarding the index, and the volumes have since had a wide distribution.

The index consists of two separate parts, each intended for a distinct purpose.

1. An index of papers in which they are classified in natural groups and arranged chronologically in each group. In each case the title and author are given, with a brief synopsis of the contents of the paper, and the names of those who took part in the discussion. Reference is given to volume number, year and page.

2. A topical index of specific data and information arranged alphabetically. This part of the index furnishes a guide to all the information contained in the TRANSACTIONS, and is grouped naturally under nouns and phrases, followed by modifying adjectives and sub-classes, all arranged alphabetically.

An index arranged on a similar plan, covering the matter contained in the papers and discussions during the year, is now published in each annual volume of the TRANSACTIONS, beginning with 1911.

Public Policy Committee.—The Public Policy Committee has held three meetings to consider and report upon matters referred to it by the President and Board of Directors; namely, the matter of sending a memorial to the President of the United States urging the appointment of one or more engineers on the Interstate Commerce Commission; to consider the continuation of the Institute's representation on the Advisory Board of the National Conservation Congress; and, to consider the invitation from the Secretary of the Interior, to confer with him on the subject of proposed legislation to govern the issue of permits for hydroelectric development on the public domain.

Patent Committee.—At the request of the Patent Committee a meeting of the Public Policy Committee was called in April to consider certain information which had been brought to the attention of the chairman of the Patent Committee in regard to the U. S. Patent Office. As a result of the meeting the Public Policy Committee recommended the appointment of a special committee of the Institute to appear before the House Committee on Appropriations, in Washington, and urge the inclusion in the Sundry Civil Bill of the sum requested by the Hon. Thomas Ewing, Commissioner of Patents, for the preparation of plans for a new Patent Office.

Committee on Relations of Consulting Engineers.—This committee has kept in touch with the practise and experience of the American Institute of Consulting Engineers in the use of the schedule of recommended charges adopted by that Institute, and has collected valuable data relating to the regulations governing the fees of architects and consulting engineers as adopted in certain foreign countries.

Committee on Code of Principles of Professional Conduct.—This committee has had nothing referred to it for action during the year. The code as adopted two years ago has been used as a basis by other societies and organizations for the formulation of codes of ethics or principles of professional conduct for themselves.

Constitutional Revision Committee.—As reported to the Board last January, the general sentiment of the Constitutional Revision Committee was that the best interests of the Institute would be served by not initiating any amendments to the Constitution this year. There are a number of minor points in the Constitution which could be made clearer or more consistent. Such changes might best be brought to the attention of the membership for vote when important constitutional changes are also to be voted upon.

It is thought by the committee that the present Constitution goes too much into detail with reference to certain matters, particularly concerning committees. The duties of certain committees, presumably the Executive Committee, the Board of Examiners, the Tellers, Finance, Sections, Editing, and Meetings and Papers Committees, should be dealt with in the Constitution. The other committees might be more properly regulated by the by-laws.

U.S. National Committee, International Electrotechnical Commission.—The Commission held a meeting in Berlin in September, 1913. The U. S. National Committee was represented at this meeting by President Mailloux and Messrs. Bell, Hobart, Kennelly, and Sharp. An advance report of the meeting was prepared by the Secretary of the American delegation and printed in the Institute PROCEEDINGS for November 1913, pp. 2148-2162.

Since the date of the last committee report in May 1913 the following publications have been issued by the Central Office:

June 1913, No. 23	List of Members
June 1913, No. 24	Fourth Annual Report to December 1912
Nov. 1913, No. 25	Résumé of Meetings of Special Committees held in Berlin, September 1913.
Dec. 1913, No. 26	Résumé of Meetings of Special Committees held in Berlin, September 1913.
Jan. 1914, No. 27	International Symbols Adopted at Berlin, September 1913.
Mar. 1914, No. 28	International Standard of Resistance for Copper.

Several meetings of the committee have been held during the year and communication has been maintained with the other national committees, on various topics, through the Central Office in London.

In many ways the I. E. C. has accomplished and is accomplishing results of widespread benefit. The U. S. National Committee continues to take a prominent and active part in this work as it has in the past.

Committee on Organization of International Electrical Congress.—During the year ending April 30, 1914, the work of organizing the International Electrical Congress has taken definite form. Early in the year the Executive Committee of the Committee on Organization was reorganized with a chairman, a vice-chairman and seven members, most of whom are chairmen of sub-committees charged with the responsibility of the proper conduct of certain phases of congress work. An Honorary President and Honorary Secretary of the Congress were also appointed, both of whom are *ex officio* members of the Executive Committee.

President Mailloux also appointed as Honorary Members of the Committee on Organization prominent engineers in foreign countries, bringing the total membership of the committee up to about 335 members.

The Executive Committee has been invested with plenary powers to conduct the organization work on behalf of the committee at large.

A number of important steps were taken by the Executive Committee during the year toward promoting the successful organization of the Congress. Membership fees were fixed at the lowest practicable point, with the object in view of securing the widest possible dissemination of the Congress transactions and the largest practicable membership.

Invitations to subscribe to membership in the Congress were issued beginning about March 1, 1914. These were sent first to Institute members, and are now being issued in European countries. Invitations to present papers before the Congress have been issued to a carefully selected list of approximately 150 engineers in countries other than the United States. Similar invitations will shortly be issued to American engineers. Steps are being taken to secure official governmental representation in the Congress.

The committee reports an encouraging display of interest in the Congress, and the conditions appear propitious for a highly successful and very useful Congress.

Edison Medal.—By the unanimous vote of all of the members of the Edison Medal Committee, the fifth Edison Medal was awarded on December 10, 1913, to Mr. Charles F. Brush, of Cleveland, Ohio, "for meritorious achievement in the invention and development of the series arc lighting system." The presentation will be made during the Annual Convention at Detroit.

Board of Examiners.—The Board of Examiners has held 11 meetings during the year. It has examined and referred to the Board of Directors with its recommendations a total of 1373 applications of all classes. A summary of these is as follows:

Recommended for election to the grade of Associate	685	
Recommended for election to the grade of Member	45	
Recommended for election to the grade of Fellow	3	
Not recommended for election to the grade of Associate	1	
Not recommended for election to the grade of Member	9	
Recommended for enrolment as students	519	1,262
Recommended for transfer to the grade of Member	46	
Not recommended for transfer to the grade of Member	20	
Recommended for transfer to the grade of Fellow	34	
Not recommended for transfer to the grade of Fellow	11	111
Total number of applications considered		1,373

Membership.—The Membership Committee deemed it inadvisable to attempt a membership campaign by direct circulation of literature soliciting new members. It was felt that this work could be carried on to better advantage through the Sections, and accordingly, a circular letter was issued inviting their coöperation. Many of the Sections have active membership committees and all of them are coöperating in advancing the interest of the Institute by obtaining desirable new members. The following table shows the number of members in each grade, the total membership, and the additions and deductions which have been made during the year.

	Honorary Member	Fellow	Member	Associate	Total
Membership, April 30, 1913.	5	316	847	6486	7654
Additions:					
Elected	1	4	42	700	
Transferred		121	264		
Reinstated			6	44	
Deductions:					
Died	1	1	7	28	
Resigned		1	6	138	
Dropped			9	384	
Transferred			110	275	
Membership, April 30, 1914.	5	439	1027	6405	7876

Net increase in membership during the year.................... 222

Deaths.—The following deaths have occurred during the year:

Honorary Member.—Sir William H. Preece.

Fellow.—Stephen D. Field.

Members.—Julius C. Calisch, Richard N. Dyer, Edwin J. Houston, Francis W. Jones, F. V. T. Lee, W. D. Marks, W. A. Pearson.

Associates.—L. E. Beilstein, R. E. Bowser, E. A. Byrnes, J. R. Calhoon, M. M. Corbin, C. E. Delafield, R. M. Ferris, E. M. Filine, H. H. Fulton, L. J. Gallagher, P. F. Harbolt, L. D. Hitzeroth, R. M. Hopkins, George R. Kempton, J. A. Kraeuchi, A. W. Lindgren, L. N. Peart, William Pitt, David H. Roberts, A. G. Rodgers, Eugene Romig, Clinton B. Smith, Wilson B. Strong, H. H. Struthers, C. Edgar Titzel, George Westinghouse, C. W. Whitman, Sidney Woodfield.

Total deaths, 37.

Finance Committee.—The following correspondence and financial statements form a complete summary of the work of the Finance Committee for the year.

NEW YORK, May 12, 1914.

BOARD OF DIRECTORS,
American Institute of Electrical Engineers.

Gentlemen:

Your Finance Committee respectfully submits the following report for the year ending April 30, 1914.

During the past year the committee has held monthly meetings, has passed upon the expenditures of the Institute for various purposes, and otherwise performed the duties prescribed for it in the Constitution and By-laws. Haskins and Sells, chartered accountants, have audited the Institute books, and their certification of the Institute finances follows.

In company with your Secretary and a member of the firm of chartered accountants, the committee has examined the securities held by the Institute and finds them to be as stated in the accountants' report.

Early in 1913, in consequence of certain extraordinary expenses incurred during the previous year, the Board was obliged to negotiate a loan of $10,000 in order to meet the Institute's current obligations. The note was taken up several months later, when funds began to accumulate through the payment of dues, but it appeared inevitable at the time that a similar condition must arise early in the present year. Such, however, has not been the case; the income from dues has been sufficient to meet all expenditures and to take up the note referred to, without in any way curtailing the Institute's activity. In fact, its field has broadened considerably during the year.

It will be noted that there is a surplus of $14,966.30 for the fiscal year. Of this amount, $3,805.94 is made up of accessions to the Library—volumes and fixtures and to works of art.

A change has been made in the form of the report, which will be particularly noted in Exhibit B, the report for the past fiscal year stating the revenue and the expenses for the year, in place of receipts and disbursements. This change we believe will show more clearly the financial operations than the form previously employed.

It will also be noted that the financial affairs of the Institute are in excellent condition, and there is every reason to anticipate that the coming year will prove equally prosperous, which should enable the Institute to take care of the amount it has underwritten in connection with the International Electrical and International Engineering Congresses, to be held in 1915, without impairment of its invested surplus.

Respectfully submitted,

J. FRANKLIN STEVENS,
Chairman Finance Committee

AMERICAN INSTITUTE OF

GENERAL BALANCE SHEET

EXHIBIT A.

ASSETS.

LAND AND BUILDING:			
Interest in United Engineering Society's Real Estate, No. 25 to 33 West 39th Street:			
Building		$353,346.61	
One-third Cost of Land		180,000.00	
Total Land and Building			$533,346.61
EQUIPMENT:			
Library—Volumes and Fixtures		$38,387.30	
Works of Art, Paintings, etc.		3,001.35	
Office Furniture and Fixtures		10,786.11	
Total Equipment			52,174.76
INVESTMENTS:			
Bonds:			
New York City, 4½%, 1917, Par $8,000.00		$8,362.50	
New York City, 4½%, 1957, Par $22,000.00		23,590.00	
City of Wilmington, Delaware, 4½%, 1934, Par $15,000.00		15,997.50	
Chicago, Burlington & Quincy Railroad Company, 4%, 1958, Par $15,000.00		14,606.25	
Total Investments			62,556.25
WORKING ASSETS:			
Publications entitled "Transactions," etc.		$8,674.25	
Badges		911.15	
Total Working Assets			9,585.4
CURRENT ASSETS:			
Cash		$3,410.26	
Accounts Receivable:			
Members for entrance fees and past dues		9,640.50	
Advertisers		1,564.75	
Miscellaneous		999.15	
Interest Accrued—Investments		831.25	
Interest Accrued—Bank Balances		77.17	
Total Current Assets			16,523.08
FUNDS:			
Land, Building, and Endowment Fund:			
Cash	$7,513.54		
Interest Accrued	78.20		
		$7,591.74	
Life Membership Fund:			
Cash	$5,431.91		
Interest Accrued	69.00		
		5,500.91	
International Electrical Congress of St. Louis—Library Fund:			
Cash	$566.24		
New York City Bonds, 4½%, 1957, Par $2,000.00	2,268.00		
Interest Accrued	45.00		
		2,879.24	
MAILLOUX FUND:			
Cash	95.80		
New York Telephone Company Bond, 4½%, 1939	1,000.00		
Interest Accrued	22.50		
		1,118.30	
Total Funds			17,090.19
Total			$691,276.29

ELECTRICAL ENGINEERS

APRIL 30, 1914

LIABILITIES.

Bond and Mortgage—United Engineering Society—One-third Interest in Land, 25 to 33 West 39th Street		$54,000.00
CURRENT LIABILITIES:		
Accounts Payable—Subject to Approval by the Finance Committee	5,561.78	
Interest Accrued on Bond and Mortgage	720.00	
Members' dues paid in advance	814.75	
Entrance fees and dues advanced by applicants for membership	72.00	
Total Current Liabilities		7,168.53
RESERVES:		
Land, Building and Endowment Fund	$7,591.74	
Life Membership Fund	5,500.91	
Mailloux Fund	1,118.30	
International Electrical Congress of St. Louis—Library Fund	2,870.24	
Total Funds	17,090.19	
Reserve for Depreciation of Furniture and Fixtures	4,867.78	
Total Reserves		21,957.97
SURPLUS: Per Exhibit "B"		608,149.79
Total		$691,276.29

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

STATEMENT OF INCOME AND PROFIT AND LOSS

FOR THE YEAR ENDED APRIL 30, 1914

EXHIBIT B.

REVENUE:			
Entrance Fees		$4,228.75	
Dues		85,915.63	
Students' Dues		4,245.00	
Transfer Fees		670.00	
Advertising		10,041.92	
Subscriptions		3,061.70	
Sales of "Transactions," etc.		2,408.12	
Badges Sold	$2,104.00		
Less Cost	1,644.81	459.19	
Interest on Investments		2,626.00	
Interest on Bank Balances		316.69	
Exchange		24.94	
Total			$113,997.94
EXPENSES:			
Meetings and Papers Committee:			
Salaries		$4,300.00	
Binding and Mailing Proceedings		4,807.60	
Printing Proceedings		8,504.86	
Engraving Proceedings		1,022.57	
Paper and Cover Paper		5,056.94	
Envelopes		821.12	
Stationery and Miscellaneous Printing		133.47	
General Expense		148.71	
Meetings		6,106.69	
Volume No. 30		3.00	
Volume No. 31		11,892.31	
Total		$42,797.87	
Deduct Increase in Inventory of Publications:			
May 1, 1913	$7,628.25		
April 30, 1914	8,674.25	1,046.00	$41,751.87
Executive Department:			
Salaries		$14,842.00	
General Expense		1,645.17	
United Engineering Society—Assessments		3,375.00	
Express		206.65	
Postage		3,602.62	
Advertising		2,010.95	
Office Furniture and Fixtures		287.72	
Stationery and Miscellaneous Printing		3,600.13	
Year Book and Catalogue		2,687.49	
Interest on Bond and Mortgage		2,160.00	
Interest on Note Payable		18.75	
Engraving		13.06	34,449.54
Forward			$76,201.41
REVENUE—(Forward)			$113,997.94

REVENUE—(Forward)		$113,997.94
EXPENSES—(Forward)		76,201.41
Sections Committee:		
Section Meetings	$3,651.32	
Branch Meetings	224.58	
Delegates Convention Expenses	1,613.36	
Salary and Traveling Expenses, Honorary Secretary	4,353.78	
Salaries, New York Office	2,268.00	
Stationery and Printing, New York Office,	674.22	
Express on Advance Copies	61.56	12,846.82
General:		
Library	$3,310.66	
Indexing "Transactions,"	1,832.21	
International Electrotechnical Commission	275.54	
Finance Committee	150.00	
Standards Committee	612.60	
President's Special Appropriation	228.30	
Annual Function	365.00	
Law Committee	500.00	
International Engineering Congress, 1915	875.00	
International Illumination Committee	100.00	
Membership Committee	4.25	8,253.56
Add:		
Increase in Accounts Payable—Subject to Approval by the Finance Committee, Undistributed at:		
May 1, 1913	$4,335.91	
April 30, 1914	5,561.78	1,225.87
Total Expenses		$98,527.66
NET REVENUE		$15,470.28
PROFIT & LOSS CREDITS:		
Accessions:		
Library Volumes and Fixtures	$3,460.94	
Works of Art	345.00	
Total		3,805.94
GROSS SURPLUS FOR THE YEAR		$19,276.22
PROFIT & LOSS CHARGES:		
Uncollectible Dues Written Off	$3,180.00	
Reservation for Depreciation of Furniture and Fixtures	1,129.83	
Total		4,309.83
NET SURPLUS FOR THE YEAR		$14,966.39
SURPLUS, MAY 1, 1913		593,183.40
SURPLUS, APRIL 30, 1914		$608,149.79

NEW YORK, May 11, 1914.

American Institute of Electrical Engineers,
33 West 39th Street, New York.
Dear Sirs:

Pursuant to engagement, we have audited the books and accounts of the American Institute of Electrical Engineers for the year ended April 30, 1914, and submit herewith our certificate and the following described exhibits:

EXHIBIT
"A"—General Balance Sheet—April 30, 1914.
"B"—Statement of Income and Profit & Loss for the Year Ended April 30, 1914.

Yours truly,
(Signed) HASKINS & SELLS
Certified Public Accountants.

CERTIFICATE

We have audited the books and accounts of the American Institute of Electrical Engineers for the year ended April 30, 1914, and

WE HEREBY CERTIFY that the accompanying General Balance Sheet properly sets forth the financial condition of the Institute on April 30, 1914, that the Statement of Income and Profit & Loss for the year ended on that date is correct, and that the books of the Institute are in agreement therewith.

(Signed) HASKINS & SELLS
Certified Public Accountants.

NEW YORK,
May 11, 1914.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS

STATEMENT OF CASH RECEIPTS AND DONATIONS FOR DESIGNATED PURPOSES. ALSO DISBURSEMENTS, FOR THE YEAR ENDED APLIL 30, 1914.

EXHIBIT C.

RECEIPTS AND DONATIONS:	
Land, Building and Endowment fund—Donations, Interest, etc.	$398.22
Life Membership Fund	362.92
International Electrical Congress of St. Louis Library Fund Donations, and Interest	94.15
Mailloux Fund, Interest	45.00
General Library Fund, Interest	6.97
Total	$907.26
DISBURSEMENTS:	
Life Membership Fund	$456.88
General Library Fund	284.92
Mailloux Fund	26.75
Weaver Fund	6.69
Total	775.24

RECEIPTS AND DISBURSEMENTS PER YEAR PER MEMBER.

During each fiscal year for the past eight years.

Year ending April 30	1907	1908	1909	1910	1911	1912	1913	1914
Membership, April 30, each year	4521	5674	6400	6681	7117	7459	7654	7876
Receipts per Member	$12.21	$13.01	$13.21	$13.35	$13.37	$13.19	$13.45	$14.08
Disbursements per Member	11.62	11.73	10.49	12.03	11.03	12.44	15.57	12.86
Credit Balance per Member	$ .59	$1.28	$2.72	$1.32	$2.34	$ .75	*$2.12	$1.22

*Deficit.

Respectfully submitted for the Board of Directors,

F. L. HUTCHINSON, *Secretary.*

New York, May 19, 1914.

SYNOPTICAL AND TOPICAL

INDEX

OF

A.I.E.E. TRANSACTIONS

Vol. XXXIII, Parts I and II

The main headings under which these synopses are classified were arrived at by a careful study of all the papers contributed since the organization of the Institute.

The method of making this classification may be called the automatic method, since it is created by sorting the papers themselves into groups and then naming the groups.

Many papers fall naturally into several different groups and in such cases they are inserted under as many different heads as it is thought they rightfully belong.

The classified synopses are designed for those searching for comprehensive information on any given topic, while the subject index is intended for those looking up specific and definite data or information.

MAIN SECTIONS OF SYNOPTICAL INDEX

Page
1. Education
2. General Theory 3
3. Units, Measurements and Instruments 5
4. Insulation and Dielectric Phenomena 7
5. Electric Conductors 10
6. Magnetic Properties and Testing of Iron 12
7. Batteries 12
8. Transformers 12
9. Electrical Machinery and Apparatus 15
10. Prime Movers and Steam Boilers 17
11. Power Plants and Central Stations 18
12. Parallel Operation
13. Transmission Lines 19
14. Electric Service Disturbances and Protection 24
15. Distribution Systems 26
16. Control, Regulation and Switching 28
17. Traction 30
18. Lighting and Lamps 33
19. Electricity in the Army and Navy 33
20. Miscellaneous Applications of Electricity 34
21. Telephony and Telegraphy 38
22. Miscellaneous Topics and Institute Affairs 40

2. GENERAL THEORY

SOLENOIDS

By Charles R. Underhill Vol. xxxiii—1914, pp. 477-509

Fundamental equation for design of solenoids and plunger magnets. Tables and curves giving constants for use in formulas. Characteristic curves of actual solenoids and plunger magnets.

Discussion, pages 510-517, by Messrs. Charles W. Burrows, E. R. Carichoff and C. R. Underhill.

Equations for magnetic field of solenoids.

SOME INVESTIGATIONS ON LIGHTNING PROTECTION FOR BUILDINGS

L. A. DeBlois Vol. xxxiii—1914, pp. 519-535

Description of investigations conducted for a large manufacturer of explosives to determine upon a suitable system of lightning protection for buildings containing explosives.

An analysis by oscillograph of the secondary currents induced by actual lightning discharges in vertical earthed conductors. Tentative explanation of the phenomena generally attributed to high frequency oscillations by the existence of unidirectional waves of almost vertical front.

An investigation of the primary effects of a 20-in. spark in air having the same essential characteristics as those attributed to lightning when applied to a model protective system consisting of isolated vertical conductors surrounding a small building.

An investigation of the secondary effects produced under the above conditions.

Brief description of a general protective system recommended for explosives buildings.

Discussion, pages 536-544, by Messrs. E. E. F. Creighton, George R. Olshausen, A. G. Webster, Elihu Thomson, W. J. Humphreys, Trygve D. Yensen and L. A. DeBlois.

Remarks on the nature of lightning and lightning strokes.

SOME SIMPLE EXAMPLES OF TRANSMISSION LINE SURGES

W. S. Franklin Vol. xxxiii—1914, pp. 545-559

Analytical discussion of waves produced in transmission lines by surging. The ribbon wave and practical examples of its application.

Discussion, pages 560-569, by Messrs. J. Murray Weed, A. G. Webster and A. Hamilton-Ellis.

Mathematical analysis of transmission line performance under surging conditions.

THEORY OF THE CORONA

Bergen Davis Vol. xxxiii—1914, pp. 589-600

Development of a theory of corona, the laws of which are based upon known principles of the motions of ions and ionization by impact.

Discussion, pages 607-617, by Messrs. J. B. Whitehead, Harris J. Ryan, Edward Bennett, Alex. Chernyshoff, F. W. Peek, Jr. and Bergen Davis.

Influence of electric field upon the molecules in decreasing the energy required for ionization. Manner in which Peek's law of visual corona was derived.

THE SPHERE GAP AS A MEANS OF MEASURING HIGH VOLTAGE

F. W. Peek, Jr. **Vol. xxxiii—1914, pp. 923-949**

Disadvantages of needle gap and advantages of sphere gap, in the measurement of high voltage. Deduction of laws for sphere gap with variations in air density. Equations for calculating sphere gap spark-over curves for various spacings, radii, air density, etc. Standard measured curves for convenient sizes of spheres at sea level with table for applying curves to any altitude. Discussion of effect of high frequency and impulse voltages. Precautions necessary in high voltage measurements with test results.

Discussion incorporated with that of paper by J. Cameron Clark and Harris J. Ryan on " Sphere Gap Discharge Voltages at High Frequencies."

THE ELECTRIC STRENGTH OF AIR—V.

The Influence of Frequency

J. B. Whitehead and W. S. Gorton **Vol. xxxiii—1914, pp. 951-972**

Description of apparatus and method of testing, and investigation of the influence of frequency on corona between 60 and 3000 cycles. Development of simple method of measuring maximum alternating e.m.f. Experimental evidence of resonance phenomena in high-tension circuits.

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J. Cameron Clark and Harris J. Ryan **Vol. xxxiii—1914, pp. 973-987**

Description of a series of experiments made to determine the values of steady high-frequency, high-voltage currents required to discharge between seven-inch copper spheres in air, at ordinary temperatures and barometric pressures.

Discussion (including that of papers by F. W. Peek, Jr. and J. B. Whitehead and W. S. Gorton), pages 988-1011, by Messrs. L. W. Chubb, F. C. Caldwell, D. M. Mahood, Charles Fortescue, D. D. Ewing, E. E. F. Creighton, H. B. Dwight, W. W. Lewis, E. P. Peck, J. R. Craighead, F. W. Peek, Jr., John B. Whitehead, M. G. Lloyd, W. B. Kouwenhoven and Harris J. Ryan.

General discussion of methods and precautions in measuring extremely high e.m.fs. Description of experiments with conductor near absolute zero of temperature, showing electrical resistance to be practically zero.

THE CORONA PRODUCED BY CONTINUOUS POTENTIALS

Stanley P. Farwell **Vol. xxxiii—1914, pp. 1631-1666**

Experimental investigation of the corona around small wires as produced by continuous potentials up to 15,000 volts, obtained from a series of 500-volt generators.

The wire and coaxial cylinder method was employed for a number of experiments. Critical voltages and characteristic potential difference and current curves for different sized wires. The effect of pressure upon appearance of corona, critical voltage, and current. Characteristic curves of the effect of varying pressure, moisture and temperature.

Discussion, pages 1667-1671, by Messrs. L. W. Chubb, A.E. Kennelly, P. M. Lincoln, Max von Recklinghausen, L. T. Robinson, Selby Haar, F. W. Peek, Jr., A. E. Kennelly and S. P. Farwell.

Comparison of a-c. with d-c. corona losses.

3. MEASUREMENTS AND INSTRUMENTS

RECORDING DEVICES

Charles P. Steinmetz **Vol. xxxiii—1914, pp. 283-292**

Fundamental types of automatic recorders. Demonstration by practical examples of usefulness of automatic recorders in operation of electric systems. Use of multi-recorder.

No discussion.

TRAFFIC STUDIES IN AUTOMATIC-SWITCHBOARD TELEPHONE SYSTEMS

W. Lee Campbell **Vol. xxxiii—1914, pp. 309-318**

Methods of observing traffic. Description of traffic-recording machine. Relative efficiency of trunk groups as shown by traffic recorder. Study of loads and determination of grouping of trunks. Charts and equations.

Discussion incorporated with that of paper by M. H. Clapp on "A Comparison of the Telegraph with the Telephone as a Means of Communication in Steam Railroad Operation."

A MILLIAMPERE CURRENT TRANSFORMER

Edward Bennett **Vol. xxxiii—1914, pp. 571-585**

The drawing and specification for a transformer for use with oscillograph for measuring current of a single insulator or a few feet of high-tension transmission line.

The transformer relations are discussed; the methods of determining the transformer constants are outlined and the performance of transformers constructed in accordance with the specifications is determined.

A series of oscillograms is given to illustrate some of the applications of the transformer, such as to the study of corona, high-tension insulators, and leakage currents in evacuated lamps.

Discussion, pages 586-588, by Messrs. J. B. Whitehead, J. R. Craighead and Edward Bennett.

Criticisms of paper.

METHODS OF KEEPING DOWN PEAKS ON POWER PURCHASED ON A PEAK BASIS

T. E. Tynes **Vol. xxxiii—1914, pp. 887-892**

Brief statement of two general ways of reducing peaks followed by description of a special peak-taking device.

Discussion, pages 893-898, by Messrs. Rudolph Tschentscher, Paul M. Lincoln, J. Lester Woodbridge, J. R. Bibbins, R. H. McLain, E. D. Dreyfus and T. E. Tynes.

General remarks on automatic peak absorption. Discussion of the economic expediency of absorbing peaks as against straight purchase of energy.

THE SPHERE GAP AS A MEANS OF MEASURING HIGH VOLTAGE

F. W. Peek, Jr. Vol. xxxiii—1914, pp. 923-949

Disadvantages of needle gap and advantages of sphere gap, in the measurement of high voltage. Deduction of laws for sphere gap with variations in air density. Equations for calculating sphere gap sparkover curves for various spacings, radii, air density, etc. Standard measured curves for convenient sizes of spheres at sea level with table for applying curves to any altitude. Discussion of effect of high frequency and impulse voltages. Precautions necessary in high voltage measurements with test results.

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General discussion of methods and precautions in measuring extremely high e. m. fs. Description of experiments with conductor near absolute zero of temperature, showing electrical resistance to be practically zero.

VOLTAGE TESTING OF CABLES

W. I. Middleton and Chester L. Dawes Vol. xxxiii—1914, pp. 1185-1206

Analysis of e. m. f. stresses in insulation. Tests that must be made, followed by description of new type of oscillating voltmeter for measuring peak values.

Discussion, pages 1207-1215, by Messrs. W. A. Del Mar, C. O. Mailloux, Henry G. Stott, E. E. F. Creighton, Charles L. Fortescue, Percy H. Thomas, J. R. Craighead, W. I. Middleton, and Chester L. Dawes.

General remarks on voltage testing of cables—what voltage, what sources. Cause of third harmonic disturbances and effect of peak e. m. f.

GRAPHIC METHOD FOR SPEED-TIME AND DISTANCE-TIME CURVES

E. C. Woodruff Vol. xxxiii—1914, pp. 1673-1676

Description of a simple method for obtaining speed-time and distance-time curves which avoids the usual step-by-step process.

Discussion, pages 1677-1719, by Messrs. Selby Haar, C. O. Mailloux, N. W. Akimoff, F. Castiglioni, F. E. Wynne, N. W. Storer, E. C. Woodruff and D. D. Ewing.

Résumé of the Mailloux method of calculating and plotting speed-time curves and comparison with the author's method. Equation for practical motor acceleration curves. Use of speed-distance curve for finding cutting off point. Use of slide rule for motor characteristic curves in speed-time curve calculations and determination of the capacity of railway motors. Castiglioni method compared with Mailloux method of speed-time calculations.

4. INSULATION AND DIELECTRIC PHENOMENA

PROBLEMS OF HIGH-TENSION TRANSMISSION LINES

Report of Sub-Committee on Transmission

Introduction by P. W. Sothman, Chairman Vol. xxxiii—1914, pp. 105-118

Outline of leading problems in building and operating high-tension lines. Selection of materials and equipment. Factors that enter into the design of the line structure. Extracts from reports of experience from various companies operating high-tension lines, with special reference to insulation.

APPENDIX I, pages 119-122. Deterioration of Porcelain Insulators in Service, by J. A. Brundige. Causes of molecular fatigue and methods of detection.

APPENDIX II, pages 123-124. Radius of Influence of a Direct Lightning Stroke, by L. C. Nicholson.

APPENDIX III, pages 124-127. Transmission Line Problems in the West, by P. M. Downing. Brief notes on experience in operation.

APPENDIX IV, pages 127-129. Switching, by G. Faccioli. Effect of switching in producing oscillations.

PRACTICAL OPERATION OF SUSPENSION INSULATORS

H. W. Buck Vol. xxxiii—1914, pp. 131-137

Brief review of difficulties experienced in operation of suspension insulators on transmission lines. Wind pressure and sleet loads. Calculation and design of lines to meet stresses.

Discussion (including that of paper by P. W. Sothman), pages 138-154, by Messrs. H. W. Buck, F. W. Peek, Jr., Charles E. Waddell, Percy H. Thomas, R. J. McClelland, V. Karapetoff, P. M. Lincoln, Farley Osgood, J. A. Sandford, Jr., E. R. Albrecht, William L. Puffer, Ernest V. Pannell, Julian C. Smith, E. A. Lof, C. O. Mailloux, E. M. Hewlett, H. W. Buck and K. C. Randall.

General remarks on transmission line construction and operation. Insulation theory and insulator troubles. Tower specifications. Choice of conductor and method of stringing. Deterioration of porcelain. Insulator design.

THEORY OF THE CORONA

Bergen Davis Vol. xxxiii—1914, pp. 589-606

Development of a theory of corona, the laws of which are based upon known principles of the motions of ions and ionization by impact.

Discussion, pages 607-617, by Messrs. J. B. Whitehead, Harris J. Ryan, Edward Bennett, Alex. Chernyshoff, F. W. Peek, Jr. and Bergen Davis.

Influence of electric field upon the molecules in decreasing the energy required for ionization. Manner in which Peek's law of visual corona was derived.

INFLUENCE OF TRANSFORMER CONNECTIONS ON OPERATION

Louis F. Blume Vol. xxxiii—1914, pp. 735-752

Discussion of relative advantages and disadvantages in operation of the more important three-phase transformer connections. Three conditions of operation are given: First, normal; second, operation of a bank with one phase disabled; third, effect of line grounds on operation. Analysis of insulation stresses at relatively low frequencies to which transformers are subject in either normal or abnormal conditions of operation. These frequencies include the fundamental or generated frequency and its harmonics and the natural frequency of the system. The behavior of three-phase auto-transformers under the various conditions of operation is also analyzed.

Discussion, incorporated with that of paper by J. P. Jollyman, P. M. Downing and F. G. Baum on "Experience of the Pacific Gas and Electric Co. with the Grounded Neutral."

THE ELECTRIC STRENGTH OF AIR—V

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General discussion of methods and precautions in measuring extremely high e.m.fs. Description of experiments with conductor near absolute zero of temperature, showing electrical resistance to be practically zero.

PROVISIONAL SPECIFICATION FOR INSULATOR TESTING

Covering Inspection and Tests of High-Tension Line Insulators of Porcelain, for over 25,000 Volts

Vol. xxxiii—1914, pp. 1107-1119

Discussion, pages 1120-1132, by Messrs. Percy H. Thomas, E. E. F. Creighton, Edward Bennett, E. M. Hewlett, Farley Osgood, S. C. Lindsay, John B. Fisken, F. W. Peek, Jr., and William B. Jackson.

General remarks on scope and character of the specifications.

VOLTAGE TESTING OF CABLES

W. I. Middleton and Chester L. Dawes Vol. xxxiii—1914, pp. 1185-1206

Analysis of e.m.f. stresses in insulation. Tests that must be made, followed by description of new type of oscillating voltmeter for measuring peak values.

Discussion, pages 1207-1215, by Messrs. W. A. Del Mar, C. O. Mailloux, Henry G. Scott, E. E. F. Creighton, Charles L. Fortescue, Percy H. Thomas, J. R. Craighead, W. I. Middleton and Chester L. Dawes.

General remarks on voltage testing of cables—what voltage, what sources. Cause of third-harmonic disturbances and effect of peak e.m.f.

ECONOMY IN THE OPERATION OF 55,000-VOLT INSULATORS

M. T. Crawford Vol. xxxiii—1914, pp. 1429-1434

Brief outline of the operating experiences on three 55,000-volt lines, two of which have been in service 10 years and one 5 years, covering the progress of insulator construction. A device is described by means of which defective insulators can be readily detected in the very early stages of deterioration.

Discussion, pages 1435-1440, by Messrs. J. Harisberger, M. H. Gerry, Jr., V. H. Greisser, A. A. Miller, H. R. Noack, T. R. Cornick, P. M. Lincoln, L. T. Merwin, L. J. Corbett, Ralph W. Pope and E. Woodbury.

Experience in the operation of high-tension insulators.

THE CORONA PRODUCED BY CONTINUOUS POTENTIALS

Stanley P. Farwell Vol. xxxiii—1914, pp. 1631-1666

Experimental investigation of the corona around small wires as produced by continuous potentials up to 15,000 volts, obtained from a series of 500-volt generators.

The wire and coaxial cylinder method was employed for a number of experiments. Critical voltages and characteristic potential difference and current curves for different sized wires. The effect of pressure upon appearance of corona, critical voltage, and current. Characteristic curves of the effect of varying pressure, moisture and temperature.

Discussion, pages 1667-1671, by Messrs. L. W. Chubb, A. E. Kennelly, P. M. Lincoln, Max von Recklinghausen, L. T. Robinson, Selby Haar, F. W. Peek, Jr., A. E. Kennelly, and S. P. Farwell.

Comparison of a-c. with d-c. corona losses.

EFFECT OF ALTITUDE ON THE SPARK-OVER VOLTAGES OF BUSHINGS, LEADS AND INSULATORS

F. W. Peek, Jr. Vol. xxxiii—1914, pp. 1721-1730

Investigation of the effect of altitude and temperature on the surface spark-over of leads and insulators. Correction factors for various standard types. Data tabulated and plotted.

Discussion incorporated with that of paper by A. O. Austin on "Insulator Depreciation and Effect on Operation."

INSULATOR DEPRECIATION AND EFFECT ON OPERATION

A. O. Austin Vol. xxxiii—1914, pp. 1731-1734

Analytical discussion of mechanical defects in line insulators as developed by actual practice. Presentation of method of calculating the probable depreciation of insulators.

Discussion (including that of paper by F. W. Peek, Jr.), pages 1745-1766, by Messrs. Harvey L. Curtis, D. B. Rushmore, E. D. Eby, P. W. Sothman, Selby Haar, Charles P. Steinmetz, E. E. F. Creighton, Farley Osgood, F. W. Peek, Jr., Edward J. Cheney, H. H. Sticht, H. H. Schneider and R. P. Jackson.

Investigation of surface resistance of various materials with quantitative results plotted as curves. General remarks on line insulators and tests for location of faulty ones.

SPECIFICATION AND ANALYTICAL PROCEDURE FOR 30 PER CENT HEVEA RUBBER INSULATING COMPOUND

Report of the Joint Rubber Insulation Committee Appointed by a Group of Manufacturers and Users of Rubber Compounds, 1911-1914

Vol. xxxiii—1914, pp. 1767-1786

Part I—General Report.
Part II—Analytical Procedure
Part III—Explanation of Procedure.
Part IV—Specification.
Part V—Explanation of Specification.

5. ELECTRIC CONDUCTORS

PRACTICAL OPERATION OF SUSPENSION INSULATORS

H. W. Buck **Vol. xxxiii—1914, pp. 131-137**

Brief review of difficulties experienced in operation of suspension-insulators on transmission lines. Wind pressure and sleet loads. Calculation and design of lines to meet stresses.

Discussion (including that of paper by P. W. Sothman), pages 138-154, by Messrs. H. W. Buck, F. W. Peek, Jr., Charles E. Waddell, Percy H. Thomas, R. J. McClelland, V. Karapetoff, P. M. Lincoln, Farley Osgood, J. A. Sandford, Jr., E. R. Albrecht, William L. Puffer, Ernest V. Pannell, Julian C. Smith, E. A. Lof, C. O. Mailloux, E. M. Hewlett, H. W. Buck and K. C. Randall.

General remarks on transmission line construction and operation. Insulation theory and insulator troubles. Tower specifications. Choice of conductor and method of stringing. Deterioration of porcelain. Insulator design.

DISTRIBUTION OF ELECTRICAL ENERGY

Report of Sub-Committee on Distribution

P. Junkersfeld, Chairman **Vol. xxxiii—1914, pp. 211-217**

General remarks on desirability of few large substations compared with many small ones. Bibliography of distribution for light, power and railways. Cables and underground construction.

APPENDIX I, pages 217-222. Three-Wire D.C. Distribution, by Philip Torchio. Brief review of practice.

APPENDIX II, pages 222-235. Alternating-Current Distribution, by H. B. Gear. Brief outline of practice for distribution of electric energy in bulk and also for general use. Typical circuits and networks. Demand factors. Advice for selection of apparatus for substations and distribution systems.

APPENDIX III, pages 236-240. Effect of Consumers' Apparatus and Wiring on Distribution, by H. Goodwin. Rules for governing consumers' load characteristics.

APPENDIX IV, pages 240-251. Direct-Current Distribution for Surface Railways—Urban Service, by R. H. Rice. General analytical discussion of the system including substations, feeders, working conductors and return.

APPENDIX V, pages 251-259. Direct-Current Distribution for Underground and Elevated Railways, by E. J. Blair. Working or contact conductor layout for different types of systems in actual use with special regard to feeding points and sectionalization.

APPENDIX VI, pages 259-261. Direct-Current Distribution for Interurban and Steam Railroads, by W. G. Carlton. Brief notes on various types and word about choice of working e.m.f.

APPENDIX VII, pages 261-262. A-C. Distribution for Interurban and Steam Railroads, by W. S. Murray. Recommendation of single-phase overhead construction.

APPENDIX VIII, pages 262-266. The Relation of Distribution Problems and Switching Apparatus, by E. B. Merriam. Brief discussion of factors most affected by switching, such as reliability of service, protection of system from disturbances, and safety of operators.

APPENDIX IX, pages 266-269. Distribution for Street Lighting Service, by Paul M. Lincoln. Advantages of constant-current series system of distribution.

Discussion, pages 270-282, by Messrs. H. L. Wallau, Philip Torchio, S. D. Sprong, D. W. Roper, E. M. Hewlett, H. R. Summerhayes, John B. Taylor, E. W. Trafford, J. T. Kelly, Jr., John Murphy, H. B. Gear and Carl Schwartz.

General remarks on operation of distribution circuits and experience with control, protective and switching apparatus of various types.

ENGINEERING DATA RELATING TO HIGH-TENSION TRANSMISSION SYSTEMS

Sub-Committee Report Prepared by the Chairman.

Vol. xxxiii—1914, pp. 1013-1089

Introduction. Classified list of power companies reporting and brief outline of scope of each report. Typical classification of information received by the committee. Drawings and tables for transmission line construction.

Discussion, pages 1090-1105, by Messrs. John B. Fisken, Percy H. Thomas, S. C. Lindsay, Ernest V. Pannell, E. E. F. Creighton, F. W. Peek, Jr., R. Fleming, H. H. Norton, M. von Recklinghausen, D. D. Ewing, R. E. Argersinger, E. A. Lof and Selby Haar.

Explanation of cause of deterioration of high-tension conductors. Operation of reverse power relays. European high-tension practice. Comprehensive list of references to high-tension engineering articles in periodicals of the world.

VOLTAGE TESTING OF CABLES

W. I. Middleton and Chester L. Dawes Vol. xxxiii—1914, pp. 1185-1206

Analysis of e.m.f. stresses in insulation. Tests that must be made, followed by description of new type of oscillating voltmeter for measuring peak values.

Discussion, pages 1207-1215, by Messrs. W. A. Del Mar, C. O. Mailloux, Henry G. Stott, E. E. F. Creighton, Charles L. Fortescue, Percy H. Thomas, J. R. Craighead, W. I. Middleton and Chester L. Dawes.

General remarks on voltage testing of cables—what voltage, what sources. Cause of third-harmonic disturbances and effect of peak, e.m.f.

A DISTRIBUTION SYSTEM FOR POWER PURPOSES

F. D. Nims **Vol. xxxiii—1914, pp. 1299-1304**

Description of the distribution system of the Western Canada Power Company, Limited, touching on the overhead and underground systems in general. Advantages obtained by duplicating lines, both for eliminating outages and from a financial standpoint. Also the advantages obtained by using a steel-taped lead-armored cable placed directly in the ground, figures showing the exact cost of such an installation being given.

Discussion, pages 1305-1313, by Messrs. J. B. Fisken, P. M. Lincoln, F. L. Rohrbach, C. S. MacCalla, H. V. Carpenter, Edward Woodbury, G. B. Rosenblatt, John Harisberger, L. J. Corbett, Paul Lebenbaum, M. T. Crawford and F. D. Nims.

Experience with underground cables without ducts.

6. MAGNETIC PROPERTIES AND TESTING OF IRON

MAGNETIC AND OTHER PROPERTIES OF ELECTROLYTIC IRON MELTED IN VACUO

Trygve D. Yensen **Vol. xxxiii—1914, pp. 451-476**

Brief mention of early work done in the study of magnetic properties of iron and iron alloys. Description of the construction of vacuum furnace for melting iron and permeameter for testing short bars. Account of methods of preparing specimens and testing their magnetic properties. Effect of heat treatment on magnetic properties shown by curves and tables. Discussion of equilibrium diagram of iron-carbon alloys with special reference to magnetic properties.

No discussion.

7. BATTERIES

SELF-CONTAINED PORTABLE ELECTRIC MINE LAMPS

H. O. Swoboda **Vol. xxxiii—1914, pp. 385-396**

General requirements of safety lamp for mines. Description of construction of groups of prize-winning electric lead storage battery safety lamps. Method of caring for lamps and batteries. Cost of operation.

Discussion, pages 397-401, by Messrs. H. H. Clark, H. H. Smith, R. C. Burrows, and H. O. Swoboda.

Advantages of the alkaline battery.

8. TRANSFORMERS

OUTDOOR SUBSTATIONS IN NEW ENGLAND

Fred L. Hunt **Vol. xxxiii—1914, pp. 65-69**

Brief description and discussion of two substations of the Amherst Power Company, giving the basis of choice between the outdoor and indoor stations. Care of transformers and oil switches in freezing weather.

Discussion incorporated with that of paper by Leslie L. Perry on " Outdoor Substations in the Middle West." .

A MILLIAMPERE CURRENT TRANSFORMER

Edward Bennett Vol. xxxiii—1914, pp. 571-585

The drawing and specification for a transformer for use with oscillograph for measuring current of a single insulator or a few feet of high-tension transmission line.

The transformer relations are discussed; the methods of determining the transformer constants are outlined and the performance of transformers constructed in accordance with the specifications is determined.

A series of oscillograms is given to illustrate some of the applications of the transformer, such as to the study of corona, high-tension insulators, and leakage currents in evacuated lamps.

Discussion, pages 586-588, by Messrs. J. B. Whitehead, J. R. Craighead and Edward Bennett.

Criticisms of paper.

EXPERIENCE WITH LINE TRANSFORMERS

D. W. Roper Vol. xxxiii—1914, pp. 686-697

Analysis of the transformer troubles for one year on a system having nearly 15,000 transformers installed. Curves showing the record of burnouts of four different makes of transformers are used as a basis for a discussion of effect of the value placed on continuous service in the selection of transformer. The results of experiment with improved lightning protection are given, showing how the troubles were reduced.

Discussion, pages 698-710, by Messrs. W. S. Moody, A. D. Fishel, H. W. Hough, Paul M. Lincoln, Joseph Franz, M. O. Troy, E. E. F. Creighton H. B. Alverson, W. L. Granger, W. J. Wooldridge and D. W. Roper.

General remarks on design, operation and protection of transformer installations.

INHERENT VOLTAGE RELATIONS IN Y AND DELTA CONNECTIONS

Royal W. Sorenson and Walter L. Newton Vol. xxxiii—1914, pp. 711-727

Results of experiments made with a miniature simple transmission system to demonstrate the inherent voltage relations with different combinations of Y and delta connections, all inductive and capacity effects in the transmission line being eliminated. The tests were made under constant conditions, with non-inductive load.

The authors give the results of four groups of tests, on four different systems of connections, pointing out the advantages and disadvantages of the several systems. In each case tests were made without load, with balanced load, and with load on one phase only, for various conditions of grounding. Typical voltage diagrams are given, to show what happens under various conditions of load.

Certain cases where the use of auto-transformers is advantageous, and the effects of different ways of connecting them, are discussed.

Discussion, pages 728-733, by Messrs. Waldo V. Lyon, A. E. Kennelly and Harold Pender, F. W. Peek, Jr., Louis F. Blume, F. C. Green, C. L. Fortescue, P. M. Lincoln, J. M. Weed and D. C. Jackson.

General remarks on the third harmonic in transformer operation.

INFLUENCE OF TRANSFORMER CONNECTIONS ON OPERATION

Louis F. Blume Vol. xxxiii—1914, pp. 735-762

Discussion of relative advantages and disadvantages in operation of the more important three-phase transformer connections. Three conditions of operation are given: First, normal; second, operation of a bank with one phase disabled; third, effect of line grounds on operation. Analysis of insulation stresses at relatively low frequencies to which transformers are subject in either normal or abnormal conditions of operation. These frequencies include the fundamental or generated frequency and its harmonics and the natural frequency of the system. The behavior of three-phase auto-transformers under the various conditions of operation is also analyzed.

Discussion incorporated with that of paper by J. P. Jollyman, P. M. Downing and F. G. Baum on " Experience of the Pacific Gas and Electric Co. with the Grounded Neutral."

A STUDY OF SOME THREE-PHASE SYSTEMS

Charles Fortescue **Vol. xxxiii—1914, pp. 753-766**

Discussion of the star-star, delta-delta, delta-star and star-delta connections in order and their individual peculiarities and characteristics, precautions that must be taken in operation to avoid trouble, and where and when the system may be grounded with best results.

Discussion incorporated with that of paper by J. P. Jollyman, P. M. Downing and F. G. Baum on " Experience of the Pacific Gas and Electric Co. with the Grounded Neutral."

EXPERIENCE OF PACIFIC GAS AND ELECTRIC CO. WITH THE GROUNDED NEUTRAL

J. P. Jollyman, P. M. Downing and F. G. Baum **Vol. xxxiii—1914, pp. 767-772**

Outline of the distributing system of the Pacific Gas and Electric Company of California which operates at 60 kv., the transformers being Y-connected, with the neutrals solidly grounded.

Discussion (including that of papers by Louis F. Blume and Charles Fortescue), pages 773-802, by Messrs. Guido Semenza, F. F. Brand, W. W. Lewis, V. M. Montsinger, C. M. Davis, L. F. Blume, H. S. Osborne, F. E. Haskell, H. S. Osborne, C. O. Mailloux, E. E. F. Creighton, John B. Taylor, F. C. Green, P. M. Lincoln, D. W. Roper, F. W. Peek, Jr., J. R. Werth, C. L. Fortescue and Max H. Collbohm.

Summary of transformer connection practice in Italy. Classification of high tension transmission systems of the world on basis of star and delta. Operating results of six great transmission systems. Results of tests on effect of capacity and inductance upon third harmonics in star auto-transformers. Comparison of star and delta from point of view of telephone disturbances. The problem of insulating transmission lines.

THE EFFECT OF DELTA AND STAR CONNECTIONS UPON TRANSFORMER WAVE FORMS

Leslie F. Curtis **Vol. xxxiii—1914, pp. 1273-1277**

Tests with the oscillograph to show the distortions in the no-load exciting current and voltage waves of three single-phase step-up transformers when the windings of the generator and both sides of the transformers were connected in all possible symmetrical delta and star relations.

Oscillograms are given in each case and the relations between the flux, voltage, exciting current, and the hysteresis cycle are shown in two instances.

Discussion, pages 1278-1282, by Messrs. P. M. Lincoln, L. J. Corbett, A. A. Miller, E. G. Robinson, Jr., M. H. Gerry, Jr., L. T. Merwin, Livingston P. Ferris, H. V. Carpenter and L. F. Curtis.

General remarks on transformer construction.

9. ELECTRICAL MACHINERY AND APPARATUS

SIXTY-CYCLE SYNCHRONOUS CONVERTERS

Vol. xxxiii—1914, pp. 353-365

L. P. Crecelius

Notes on choice of synchronous converter for sixty-cycle operation. Extracts from purchasers' contract and specifications.

No discussion.

THE DEVELOPMENT OF THE ELECTRIC MINE LOCOMOTIVE

Vol. xxxiii—1914, pp. 403-414

G. M. Eaton

Evolution of coal mine locomotive with illustrations. Various types of mine locomotives, construction shown and briefly discussed. Also brief reference to various types of motors with different methods of lubrication and bearing construction. Design data plotted to show tendency of future development.

Discussion, pages 415-429, by Messrs. W. W. Miller, C. W. Beers, Carl J. E. Waxbom, Graham Bright, F. L. Stone, G. M. Eaton, L. J. Ilsley, W. A. Thomas, G. H. Shapter, E. H. Martindale and N. W. Storer.

General remarks on constructional features of mine locomotives. Data on costs, repairs and troubles from actual experience. Experience with ball bearings.

MINE SUBSTATIONS

Motor-Generator Sets vs. Synchronous Converters

Vol. xxxiii—1914, pp. 431-437

Will H. Hoen

Comparison of synchronous converters, synchronous motor-generators and induction motor generators as to starting characteristics, efficiency and performance on mine loads.

Discussion incorporated with that of paper by H. Booker on "Mine Substations—Their Construction and Operation."

MINE SUBSTATIONS

Their Construction and Operation

Vol. xxxiii—1914, pp. 439-444

H. Booker

Brief practical discussion of layout, operation and maintenance of substations around coal mines. List of common defects in design of substations and faults in the organization of the operating force.

Discussion (including that of paper by Will M. Hoen), pages 445-449, by Messrs. W. A. Thomas, P. M. Lincoln, N. Stahl and Will M. Hoen.

Use of synchronous converters in mines. Load characteristics of mines.

SOLENOIDS

Vol. xxxiii—1914, pp. 477-509

Charles R. Underhill

Fundamental equation for design of solenoids and plunger magnets. Tables and curves giving constants for use in formulas. Characteristic curves of actual solenoids and plunger magnets.

Discussion, pages 510-517, by Messrs. Charles W. Burrows, E. R. Carichoff, and C. R. Underhill.

Equations for magnetic field of solenoids.

THE FUTURE OF ELECTRIC HEATING AND COOKING IN MARINE SERVICE

H. J. Mauger Vol. xxxiii—1914, pp. 659-668

General remarks on use and future of electric cooking on board ship. Brief description of equipment of Battleship Texas and results of tests of power consumption. Advantages of electric cooking and heating.

Discussion, pages 669-672, by Messrs. W. S. Hadaway, E. F. Dutton, H. J. Mauger and Frank T. Leilich.

Disadvantages of electric cooking on board ship. Difficulties of building resistors for high surface temperatures.

RELATIVE MERITS OF Y AND DELTA CONNECTION FOR ALTERNATORS

T. S. Eden Vol. xxxiii—1914, pp. 803-806

Brief statement of advantages and disadvantages of each system.

Discussion incorporated with that of paper by Cassius M. Davis on "Delta and Y Connections for Railway Transmission and Distribution."

ELECTRIC HEATING AS APPLIED TO MARINE SERVICE

C. S. McDowell and D. M. Mahood Vol. xxxiii—1914, pp. 839-850

A comparison of convector and radiant heaters, the proper use of each type being shown, for space heating on shipboard with metal decks and bulkheads.

Curves showing results obtained on tests to determine the best type of heater for shipboard and desirable features of heater are indicated.

Discussion, pages 851-855, by Messrs. W. S. Hadaway, Jr., Alfred E. Waller, Charles D. Knight, D. B. Rushmore, F. C. Caldwell, D. M. Mahood and H. A. Hornor.

Results of electric heating tests at the University of Nebraska. Relative merits of open-coil and enclosed heater units.

THE ELECTRICALLY DRIVEN GYROSCOPE IN MARINE WORK

H. C. Ford Vol. xxxiii—1914, pp. 867-871

Definition of gyroscope and brief statement of practical uses to which it has been put:

A general description of the gyro-compass as adopted by the United States Navy for use on all the battleships and submarine vessels, and of the many electrical and mechanical devices that have been developed by E. A. Sperry to perform the various functions whereby an instrument of great precision has been secured.

Brief mention of large gyroscopes which are capable of counteracting enormous wave forces and completely stabilizing any ship against rolling in the heaviest seas.

Discussion, page 872, by Messrs. Alfred E. Waller and H. C. Ford. Remarks on stabilizing action of gyroscope.

DIRECT-CURRENT MOTORS FOR COAL AND ORE BRIDGES

R. H. McLain Vol. xxxiii—1914, pp. 873-884

Brief description of the mechanical arrangement of a coal bridge. Performance characteristic curves and discussion of type of motors suited to the work and the proper methods of gearing the motor for most economical results.

Discussion, pages 885-886, by Messrs. D. B. Rushmore, S. C. Lindsay, T. E. Tynes and R. H. McLain.

CONCATENATED INDUCTION MOTORS FOR ROLLING MILL DRIVE

William O. Oschmann Vol. xxxiii—1914, pp. 899-920

Description of a six-speed concatenated induction motor set for driving the finishing rolls of a 12-stand continuous mill and analysis of the conditions that determined choice of prime mover and motor drive control. Load diagram and power characteristics curves.

Discussion, page 921, by Messrs. Rudolph Tschentscher, T. E. Tynes and A. E. Averrett.

APPLICATION OF ELECTRIC MOTORS TO GOLD DREDGES

Girard B. Rosenblatt Vol. xxxiii—1914, pp. 1405-1416

Classification of gold dredges and outline of requirements for electric operation. Choice of motor and specifications for design of digging motor.

Discussion, pages 1417-1427, by Messrs. Ford W. Harris, M. H. Gerry, Jr., F. A. Ross, L. K. Armstrong, W. M. Sheppard, A. A. Miller and C. B. Rosenblatt.

Experience with electric dredges.

USE OF REACTANCE WITH SYNCHRONOUS CONVERTERS

An Insurance to Continuity of Service and a Protection to Apparatus

J. L. McK. Yardley Vol. xxxiii—1914, pp. 1521-1533

Results of overload and short-circuit tests upon two synchronous converters of widely different operating characteristics in circuit with auxiliary reactors. In the one case the reactor is in the a-c. circuit and in the other in the d-c. circuit.

Division of synchronous converter installations into a few general classes with respect to the character and exactions of the service conditions under which they are required to operate with respect to the need or desirability of employing protective reactance, and also with respect to the general design or type of the reactor to be employed.

Discussion, pages 1534-1547, by Messrs. D. B. Rushmore, Philip Torchio, H. W. Buck, H. R. Summerhayes, J. J. Frank, N. W. Storer, George T. Hanchett, Carl J. Fechheimer, Mr. Woodward, Mr. Howard, Mr. Burnham, J. L. McK. Yardley and John B. Taylor.

General remarks on design and application of protective reactors.

10. PRIME MOVERS AND STEAM BOILERS

CONCATENATED INDUCTION MOTORS FOR ROLLING MILL DRIVE

William O. Oschmann Vol. xxxiii—1914, pp. 899-920

Description of a six-speed concatenated induction motor set for driving the finishing rolls of a 12-stand continuous mill and analysis of the conditions that determined choice of prime mover and motor drive control. Load diagrams and power characteristic curves.

Discussion, page 921, by Messrs. Rudolph Tschentscher, T. E. Tynes and A. E. Averrett.

PRESENT STATUS OF PRIME MOVERS

H. G. Stott, R. J. S. Pigott and W. S. Gorsuch Vol. xxxiii—1914, pp. 1133-1166

Concise presentation of the present status of heat engines and hydraulic turbines in commercial use for the conversion of the energy of fuel and water into mechanical energy for the production of electric energy.

The various types are compared as to relative importance, capacity, efficiency, weight, cost and economy, which are illustrated by curves plotted on kilowatt basis.

Curves are plotted showing the investment and fuel costs of the different heat engine units, on the basis of percentage of normal full load rating of machines.

Discussion, pages 1167-1183, by Messrs. R. Tschentscher, J. R. Bibbins, H. M. Hobart, E. D. Dreyfus, H. G. Stott, S. Barfoed, Franklin M. Farwell, W. S. Gorsuch and R. J. S. Pigott.

General remarks and data on the cost of electric energy production with different prime movers under various conditions.

11. POWER PLANTS

PROTECTIVE REACTANCE IN LARGE POWER STATIONS

James Lyman, Allen M. Rossman and Leslie L. Perry **Vol. xxxiii—1914, pp. 23-46**

General discussion of the various uses of reactance to limit the flow of energy under abnormal conditions. Typical busbar arrangements. Diagrams giving relation between maximum current and reactance used in various ways. Diagrams of relation between maximum current and number of generators running. Equation for maximum current.

Discussion, pages 46-55, by Messrs. Philip Torchio, W. S. Moody, Henry G. Stott, Paul M. Lincoln, V. Karapetoff, Harry R. Woodrow, Cassius M. Davis, Allen M. Rossman, O. J. Ferguson and Alex. E. Bauhan.

Discussion of the use and design of reactance coils. Equation for instantaneous current.

THE ECONOMICAL CAPACITY OF A COMBINED HYDROELECTRIC AND STEAM POWER PLANT

Cary T. Hutchinson **Vol. xxxiii—1914, pp. 155-192**

Development of method of determining the point of economical capacity of a hydroelectric plant on a variable-flow stream with and without pondage and with steam auxiliary. Choice of basic stream flow. Complete data on Susquehanna River as practical example. Determination of capacity of steam auxiliary. Per cent deficiency and per cent load charts for use in calculations. Cost of hydroelectric plants and energy production. Numerical examples of the use of the method.

Discussion incorporated with that of paper by H. M. Hobart on " The Cost of Electricity at the Source."

THE COST OF ELECTRICITY AT THE SOURCE

H. M. Hobart **Vol. xxxiii—1914, pp. 192-200**

The Stott-Gorsuch method is applied to the determination of the cost of manufacturing electricity in a 60-cycle station of 100,000 kilowatts installed capacity. A method is indicated for tracing through the increase in the cost of the electricity at later stages of its journey from the source to the consumer.

Discussion (including that of paper by Cary T. Hutchinson) pages 201-210, by Messrs. J. W. Lieb, Jr., H. R. Summerhayes, H. W. Buck, Frederick A. Scheffler, H. L. Wallau, H. B. Alverson, O. K. Harlan, H. C. Abell, A. H. Kruesi, V. Karapetoff, Frederick G. Strong, G. L. Knight and H. M. Hobart.

General remarks on cost of equipping electric generating stations and some actual cost data.

METHODS OF KEEPING DOWN PEAKS ON POWER PURCHASED ON A PEAK BASIS

T. E. Tynes Vol. xxxiii—1914, pp. 887-892

Brief statement of two general ways of reducing peaks followed by description of a special peak-taking device.

Discussion, pages 893-898, by Messrs. Rudolph Tschentscher, Paul M. Lincoln, J. Lester Woodbridge, J. R. Bibbins, R. H. McLain, E. D. Dreyfus and T. E. Tynes.

General remarks on automatic peak absorption. Discussion of the economic expediency of absorbing peaks as against straight purchase of energy.

ELECTRICAL FEATURES OF THE U. S. RECLAMATION SERVICE

F. H. Newell Vol. xxxiii—1914, pp. 1609-1624

Brief outline of electrical development problems of the Reclamation Service, followed by short descriptions of the chief developments. Tabulated data on the electrical installations and power plants of the Reclamation Service.

Discussion, pages 1625-1629, by Messrs. Paul Spencer, Ralph W. Pope, J. E. Kershner, P. M. Lincoln, H. A. Hornor, Vladimir Karapetoff, Carl Hering, Mr. Bender, H. Goodwin, Jr., and F. H. Newell.

General remarks on the cost of energy for hydroelectric developments.

13. TRANSMISSION

PROBLEMS OF HIGH-TENSION TRANSMISSION LINES

Report of Sub-Committee on Transmission

Introduction by P. W. Sothman, Chairman Vol. xxxiii—1914, pp. 105-118

Outline of leading problems in building and operating high-tension lines. Selection of materials and equipment. Factors that enter into the design of the line structure. Extracts from reports of experience from various companies operating high-tension lines with special reference to insulation.

APPENDIX I, pages 119-122. Deterioration of Porcelain Insulators in Service, by J. A. Brundige. Causes of molecular fatigue and methods of detection.

APPENDIX II, pages 123-124. Radius of Influence of a Direct Lightning Stroke, by L. C. Nicholson.

APPENDIX III, pages 124-127. Transmission Line Problems in the West, by P. M. Downing. Brief notes on experience in operation.

APPENDIX IV, pages 127-129. Switching, by G. Faccioli. Effect of switching in producing oscillations.

PRACTICAL OPERATION OF SUSPENSION INSULATORS

H. W. Buck Vol. xxxiii—1914, pp. 131-137

Brief review of difficulties experienced in operation of suspension insulators on transmission lines. Wind pressure and sleet loads. Calculation and design of lines to meet stresses.

Discussion (including that of paper by P. W. Sothman), pages 138-154, by Messrs. H. W. Buck, F. W. Peek, Jr., Charles E. Waddell, Percy H. Thomas, R. J. McClelland, V. Karapetoff, P. M. Lincoln, Farley Osgood, J. A. Sandford, Jr., E. R. Albrecht, William L. Puffer, Ernest V.

Pannell, Julian C. Smith, E. A. Lof, C. O. Mailloux, E. M. Hewlett, H. W. Buck and K. C. Randall.

General remarks on transmission line construction and operation. Insulation theory and insulator troubles. Tower specifications. Choice of conductor and method of stringing. Deterioration of porcelain. Insulator design.

SOME SIMPLE EXAMPLES OF TRANSMISSION LINE SURGES

W. S. Franklin **Vol. xxxiii—1914, pp. 545-559**

Analytical discussion of waves produced in transmission lines by surging. The ribbon wave and practical examples of its application.

Discussion, pages 560-569, by Messrs. J. Murray Weed, A. G. Webster and A. Hamilton-Ellis.

Mathematical analysis of transmission line performance under surging conditions.

EXPERIENCES WITH LINE TRANSFORMERS

D. W. Roper **Vol. xxxiii—1914, pp. 685-679**

Analysis of the transformer troubles for one year on a system having nearly 15,000 transformers installed. Curves showing the record of burnouts of four different makes of transformers are used as a basis for a discussion of effect of the value placed on continuous service in the selection of transformers. The results of experiment with improved lightning protection are given, showing how the troubles were reduced.

Discussion, pages 698-710, by Messrs. W. S. Moody, A. D. Fishel, H. W. Hough, Paul M. Lincoln, Joseph Franz, M. O. Troy, E. E. F. Creighton, H. B. Alverson, W. L. Granger, W. J. Wooldridge, and D. W. Roper.

General remarks on design, operation and protection of transformer installations.

INHERENT VOLTAGE RELATIONS IN Y AND DELTA CONNECTIONS

Royal W. Sorenson and Walter L. Newton **Vol. xxxiii—1914, pp. 711-727**

Results of experiments made with a miniature simple transmission system to demonstrate the inherent voltage relations with different combinations of Y and delta connections, all inductive and capacity effects in the transmission line being eliminated. The tests were made under constant conditions, with non-inductive load.

The authors give the results of four groups of tests, on four different systems of connections, pointing out the advantages and disadvantages of the several systems. In each case tests were made without load, with balanced load, and with load on one phase only, for various conditions of grounding. Typical voltage diagrams are given, to show what happens under various conditions of load.

Certain cases where the use of auto-transformers is advantageous, and the effects of different ways of connecting them, are discussed.

Discussion, pages 728-733, by Messrs. Waldo V. Lyon, A. E. Kennelly and Harold Pender, F. W. Peek, Jr., Louis F. Blume, F. C. Green, C. L. Fortescue, P. M. Lincoln, J. M. Weed and D. C. Jackson.

General remarks on the third harmonic in transformer operation.

INFLUENCE OF TRANSFORMER CONNECTIONS ON OPERATION

Louis F. Blume **Vol. xxxiii—1914, pp. 735-752**

Discussion of relative advantages and disadvantages in operation of the more important three-phase transformer connections. Three conditions of operation are given: First, normal; second, operation of a bank with one phase disabled, third, effect of line grounds on operation. Analysis of insulation stresses at relatively low frequencies to which transformers are subject in either normal or abnormal conditions of operation. These frequencies include the fundamental or generated frequency and its harmonics and the natural frequency of the system. The behavior of three-phase auto-transformers under the various conditions of operation is also analyzed.

Discussion, incorporated with that of paper by J. P. Jollyman, P. M. Downing and F. G. Baum on "Experience of the Pacific Gas and Electric Co. with the Grounded Neutral."

A STUDY OF SOME THREE-PHASE SYSTEMS

Charles Fortescue **Vol. xxxiii—1914, pp. 753-766**

Discussion of the star-star, delta-delta, delta-star and star-delta connections in order and their individual peculiarities and characteristics, precaution that must be taken in operation to avoid trouble, and where and when the system may be grounded with best results.

Discussion incorporated with that of paper by J. P. Jollyman, P. M. Downing and F. G. Baum on "Experience of the Pacific Gas and Electric Co. with the Grounded Neutral."

EXPERIENCE OF PACIFIC GAS AND ELECTRIC CO. WITH THE GROUNDED NEUTRAL

J. P. Jollyman, P. M. Downing and F. G. Baum **Vol. xxxiii—1914, pp. 767-772**

Outline of the distributing system of the Pacific Gas and Electric Company of California which operates at 60 kv., the transformers being Y-connected, with the neutrals solidly grounded.

Discussion (including that of papers by Louis F. Blume and Charles Fortescue), pages 773-802, by Messrs. Guido Semenza, F. F. Brand, W.W. Lewis, V. M. Montsinger, C. M. Davis, L. F. Blume, H. S. Osborne, F. E. Haskell, H. S. Osborne, C. O. Mailloux, E. E. F. Creighton, John B. Taylor, F. C. Green, P. M. Lincoln, D. W. Roper, F. W. Peek, Jr., J. R. Werth, C. L. Fortescue and Max H. Collbohm.

Summary of transformer connection practice in Italy. Classification of high tension transmission systems of the world on basis of star and delta. Operating results of six great transmission systems. Results of tests on effect of capacity and inductance upon third harmonics in star autotransformers. Comparison of star and delta from point of view of telephone disturbances. The problem of insulating transmission lines.

DELTA AND Y CONNECTIONS FOR RAILWAY TRANSMISSION AND DISTRIBUTION

Cassius M. Davis **Vol. xxxiii—1914, pp. 807-810**

Brief statement of problem of selecting connections for railway system.

Discussion, (including that of paper by T. S. Eden), pages 811-817, by Messrs. John B. Taylor, C. J. Fechheimer, E. G. Merrick, T. S. Eden, R. E. Doherty, Cassius M. Davis and Selby Haar.

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Introduction. Classified list of power companies reporting and brief outline of scope of each report. Typical classification of information received by the committee. Drawings and tables for transmission line construction.

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Explanation of cause of deterioration of high-tension conductors. Operation of reverse power relays. European high-tension practice. Comprehensive list of references to high-tension engineering articles in periodicals of the world.

PROVISIONAL SPECIFICATION FOR INSULATOR TESTING

Covering Inspection and Tests of High-Tension Line Insulators of Porcelain, for over 25,000 Volts

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150,000-VOLT TRANSMISSION SYSTEM

Some Operating Conditions of the Big Creek Development of the Pacific Light & Power Corporation

Edward Woodbury Vol. xxxiii—1914, pp. 1283-1294

Description of operating conditions on the 150,000-volt transmission 240-mile line of the Pacific Light and Power Corporation.

Appendixes describe the development of the system, and give comprehensive data relating to the equipment of the Big Creek transmission line.

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Early experience with high-tension lines in the West. Necessity of synchronous condenser for very high-tension operation of long lines.

A DISTRIBUTION SYSTEM FOR POWER PURPOSES

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Description of the distribution system of the Western Canada Power Company, Limited, touching on the overhead and underground systems in general. Advantages obtained by duplicating lines, both for eliminating outages and from a financial standpoint. Also the advantages obtained by using a steel-taped lead-armored cable placed directly in the ground, figures showing the exact cost of such an installation being given.

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M. T. Crawford **Vol. xxxiii—1914, pp. 1429-1434**

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EFFECT OF ALTITUDE ON THE SPARK-OVER VOLTAGES OF BUSHINGS, LEADS AND INSULATORS

F. W. Peek, Jr. **Vol. xxxiii—1914, pp. 1721-1730**

Investigation of the effect of altitude and temperature on the surface spark-over of leads and insulators. Correction factors for various standard types. Data tabulated and plotted.

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INSULATOR DEPRECIATION AND EFFECT ON OPERATION

A. O. Austin **Vol. xxxiii—1914, pp. 1731-1734**

Analytical discussion of mechanical defects in line insulators as developed by actual practice. Presentation of method of calculating the probable depreciation of insulators.

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Investigation of surface resistance of various materials with quantitative results plotted as curves. General remarks on line insulators and tests for location of faulty ones.

SPECIFICATION AND ANALYTICAL PROCEDURE FOR 30 PER CENT HEVEA RUBBER INSULATING COMPOUND

Report of the Joint Rubber Insulation Committee Appointed by a Group of Manufacturers and Users of Rubber Compounds, 1911-1914

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14. ELECTRIC SERVICE DISTURBANCES AND PROTECTION

PROBLEMS OF HIGH-TENSION TRANSMISSION LINES

Report of Sub-Committee on Transmission

Introduction by P. W. Sothman, Chairman Vol. xxxiii—1914, pp. 105-118

Outline of leading problems in building and operating high-tension lines. Selection of materials and equipment. Factors that enter into the design of the line structure. Extracts from reports of experience from various companies operating high-tension lines with special reference to insulation.

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THE PRESENT STATUS OF ALUMINUM-CELL LIGHTNING ARRESTERS

E. E. F. Creighton Vol. xxxiii—1914, pp. 293-300

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Discussion, pages 301-308, by Messrs. V. Karapetoff, F. W. Peek, Jr., L. C. Nicholson, C. O. Mailloux, C. P. Steinmetz and E. E. F. Creighton.

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SOME INVESTIGATIONS ON LIGHTNING PROTECTION FOR BUILDINGS

L. A. DeBlois Vol. xxxiii—1914, pp. 519-535

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An analysis by oscillograph of the secondary currents induced by actual lightning discharges in vertical earthed conductors. Tentative explanation of the phenomena generally attributed to high-frequency oscillations by the existence of unidirectional waves of almost vertical front.

An investigation of the primary effects of a 20-in. spark in air having the same essential characteristics as those attributed to lightning when applied to a model protective system consisting of isolated vertical conductors surrounding a small building.

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General remarks on design, operation and protection of transformer installations.

VOLTAGE TESTING OF CABLES

W. I. Middleton and Chester L. Dawes **Vol. xxxiii—1914, 1185-1206**

Analysis of e. m. f. stresses in insulation. Tests that must be made, followed by description of new type of oscillating voltmeter for measuring peak values.

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General remarks on voltage testing of cables—what voltage, what sources. Cause of third harmonic disturbances and effect of peak e. m. f.

PROTECTIVE REACTORS FOR FEEDER CIRCUITS OF LARGE CITY POWER SYSTEMS

James Lyman, Leslie L. Perry and A. M. Rossman **Vol. xxxiii—1914, pp. 1509-1519**

Outline of the use and limitations of protective reactance coils in feeder circuits. Curves given showing what the effects of feeder reactors are, with and without bus reactors, for generators of various reactances. The advantages that might be gained by parallel operation of feeders are discussed and the difficulties to be encountered are pointed out.

Discussion incorporated with that of paper by J. L. McK. Yardley on "Use of Reactance with Synchronous Converters."

USE OF REACTANCE WITH SYNCHRONOUS CONVERTERS

An Insurance to Continuity of Service and a Protection to Apparatus.

J. L. McK. Yardley **Vol. xxxiii—1914, pp. 1521-1533**

Results of overload and short-circuit tests upon two synchronous converters of widely different operating characteristics in circuit with auxiliary reactors. In the one case the reactor is in the a-c. circuit and in the other in the d-c. circuit.

Division of synchronous converter installations into a few general classes with respect to the character and exactions of the service conditions under which they are required to operate with respect to the need of desirability of employing protective reactance, and also with respect to the general design or type of the reactor to be employed.

Discussion, pages 1534-1547, by Messrs. D. B. Rushmore, Philip Torchio, H. W. Buck, H. R. Summerhayes, J. J. Frank, N. W. Storer, George T. Hanchett, Carl J. Fechheimer, Mr. Woodward, Mr. Howard, Mr. Burnham, J. L. McK. Yardley and John B. Taylor.

General remarks on design and application of protective reactors.

15. DISTRIBUTION SYSTEMS

OUTDOOR VS. INDOOR SUBSTATIONS

Alexander Macomber **Vol. xxxiii—1914, pp. 57-63**

Brief review of the types of apparatus that have been developed for outdoor substation operation. Classification of outdoor substations according to application, and discussion of each. Relative merits of outdoor and indoor substations.

Discussion incorporated with that of paper by Leslie L. Perry on " Outdoor Substations in the Middle West."

OUTDOOR SUBSTATIONS IN NEW ENGLAND

Fred L. Hunt **Vol. xxxiii—1914, pp. 65-69**

Brief description and discussion of two substations of the Amherst Power Company, giving the basis of choice between the outdoor and indoor stations. Care of transformers and oil switches in freezing weather.

Discussion incorporated with that of paper by Leslie L. Perry on " Outdoor Substations in the Middle West."

INDOOR AND OUTDOOR SUBSTATIONS IN PENNSYLVANIA

H. L. Fullerton **Vol. xxxiii—1914, pp. 71-87**

General analysis of substations designed for primary voltages below 20,000. Both indoor and outdoor types considered, being classified under the heads: Customers' stations fed from distribution, customers' stations fed from transmission system, company's stations. Selection of location, type of building, apparatus, etc. Relative costs of different types of construction. General layouts for typical bus arrangements. Relative merits of outdoor and indoor stations.

Discussion incorporated with that of paper by Leslie L. Perry on " Outdoor Substations in the Middle West."

OUTDOOR SUBSTATIONS IN THE MIDDLE WEST

Leslie L. Perry **Vol. xxxiii—1914, pp. 89-91**

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DISTRIBUTION OF ELECTRICAL ENERGY

Report of Sub-Committee on Distribution

P. Junkersfeld, Chairman **Vol. xxxiii—1914, pp. 211-217**

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MINE SUBSTATIONS
Their Construction and Operation

H. Booker Vol. xxxiii—1914, pp. 439-444

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A DISTRIBUTION SYSTEM FOR POWER PURPOSES

F. D. Nims Vol. xxxiii—1914, pp. 1299-1304

Description of the distribution system of the Western Canada Power Company, Limited, touching on the overhead and underground systems in general. Advantages obtained by duplicating lines, both for eliminating outages and from a financial standpoint. Also the advantages obtained by using a steel-taped lead-armored cable placed directly in the ground, figures showing the exact cost of such an installation being given.

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16. CONTROL, REGULATION AND SWITCHING

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RECORDING DEVICES

Charles P. Steinmetz **Vol. xxxiii—1914, pp. 283-292**

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MINE DUTY CONTROLLERS

Harrison P. Reed **Vol. xxxiii—1914, pp. 367-375**

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CONCATENATED INDUCTION MOTORS FOR ROLLING MILL DRIVE

William O. Oschmann **Vol. xxxiii—1914, pp. 899-920**

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17. TRACTION

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M. H. Clapp **Vol. xxxiii—1914, pp. 319-338**

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THE DEVELOPMENT OF THE ELECTRIC MINE LOCOMOTIVE

G. M. Eaton **Vol. xxxiii—1914, pp. 403-414**

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18. LIGHTING AND LAMPS

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19. ELECTRICITY IN THE ARMY AND NAVY

ELECTRICITY THE FUTURE POWER FOR STEERING VESSELS

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THE FUTURE OF ELECTRIC HEATING AND COOKING IN MARINE SERVICE

H. J. Mauger **Vol. xxxiii—1914, pp. 659-668**

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Disadvantages of electric cooking on board ship. Difficulties of building resistors for high surface temperatures.

ELECTRIC HEATING AS APPLIED TO MARINE SERVICE

C. S. McDowell and D. M. Mahood **Vol. xxxiii—1914, pp. 839-850**

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Results of electric heating tests at the University of Nebraska. Relative merits of open-coil and enclosed heater units.

THE ELECTRICALLY DRIVEN GYROSCOPE IN MARINE WORK

H. C. Ford **Vol. xxxiii—1914, pp. 857-871**

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A general description of the gyro-compass as adopted by the United States Navy for use on all the battleships and submarine vessels, and of the many electrical and mechanical devices that have been developed by E. A. Sperry to perform the various functions whereby an instrument of great precision has been secured.

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H. A. Hornor **Vol. xxxiii—1914, pp. 1567-1592**

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Harrison P. Reed **Vol. xxxiii—1914, pp. 367-375**

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MINE SUBSTATIONS

Motor-Generator Sets vs. Synchronous Converters

Will M. Hoen **Vol. xxxiii—1914, pp. 431-437**

Comparison of synchronous converters, synchronous motor-generators and induction motor-generators as to starting characteristics, efficiency and performance on mine loads.

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MINE SUBSTATIONS

Their Construction and Operation

H. Booker **Vol. xxxiii—1914, pp. 439-444**

Brief practical discussion of layout, operation and maintenance of substations around coal mines. List of common defects in design of substations and faults in the organization of the operating force.

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MAGNETIC AND OTHER PROPERTIES OF ELECTROLYTIC IRON MELTED IN VACUO

Trygve D. Yensen Vol. xxxiii—1914, pp. 451-476

Brief mention of early work done in the study of magnetic properties of iron and iron alloys. Description of the construction of vacuum furnace for melting iron and permeameter for testing short bars. Account of methods of preparing specimens and testing their magnetic properties. Effect of heat treatment on magnetic properties shown by curves and tables. Discussion of equilibrium diagram of iron-carbon alloys with special reference to magnetic properties.

No discussion.

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C. Edward Magnusson and B. Izhuroff Vol. xxxiii—1914, pp. 673-684

Results of prolonged tests to corroborate results given in former paper (Vol. XXX, page 2055). Description of apparatus and tabulation of results.

No discussion.

ELECTRIC HEATING AS APPLIED TO MARINE SERVICE

C. S. McDowell and D. M. Mahood Vol. xxxiii—1914, pp. 839-850

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Brief mention of large gyroscopes which are capable of counteracting enormous wave forces and completely stabilizing any ship against rolling in the heaviest seas.

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R. H. McLain **Vol. xxxiii—1914, pp. 873-884**

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CONCATENATED INDUCTION MOTORS FOR ROLLING MILL DRIVE

William O. Oschmann **Vol. xxxiii—1914, pp. 899-920**

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STERILIZATION OF WATER BY ULTRA-VIOLET RAYS OF THE MERCURY-VAPOR QUARTZ LAMP

M. von Recklinghausen **Vol. xxxiii—1914, pp. 1217-1230**

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E. F. Whitney **Vol. xxxiii—1914, pp. 1315-1354**

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Girard B. Rosenblatt **Vol. xxxiii—1914, pp. 1405-1416**

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F. H. Newell **Vol. xxxiii—1914, pp. 1609-1624**

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EXPERIENCE OF PACIFIC GAS AND ELECTRIC CO. WITH THE GROUNDED NEUTRAL

J. P. Jollyman, P. M. Downing and F. G. Baum Vol. xxxiii—1914, pp. 767-772

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Carl Kinsley Vol. xxxiii—1914, pp. 1243-1253

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An Experimental Study of the Relationship between Circuit Loads and Delay to Traffic.

Frank F. Fowle Vol. xxxiii—1914, pp. 1263-1270

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